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On the Fishing Effort in English Demersal Fisheries

J. A. GULLAND, B.A.

Fisheries Laboratory, Lowestoft

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On the Fishing Effort in English Demersal Fisheries

INTRODUCTION

THE STUDY of an exploited fish population a most important factor is the fishing ort expended. Together with a knowledge of the commercial catch, the effort may be ed to calculate the catch-per-unit-effort, which provides one of the most useful and dely applied indices of abundance of the exploited stock. A knowledge of the effort is en more important when assessing the relations between the activities of the commercial et and the mortality observed in the fish stock, and hence in evaluating the possibility over-fishing and the effects of any conservation measures.

Following Beverton and Holt (in press) the effort expended by a particular vessel may defined as the product of the fishing power of that vessel and an appropriate measure the time spent fishing. The fishing power may be defined by reference to a standard ssel by comparing their catches when fishing at the same time and place. For a gear ıich, when in operation, may be considered as catching fish continuously, e.g. a trawl, e duration of the fishing is best measured by the number of hours the gear is actually in eration. In other gears, e.g. ring-nets, it may be better measured in terms of the number operations, e.g. shots. Practical, though theoretically less desirable, measures of the tent of operation of a vessel, are the time spent at sea, the time on the fishing ground, d the number of trips.

Even neglecting variations on skill of skipper and crew, no two ships in a commercial et will have exactly the same fishing power. Thus, changes in the composition of the mmercial fleet will be reflected in changes in the average fishing power. Then estimates effort, and catch per unit effort, based on the assumption of constant fishing power, will distorted. This is particularly important when, as is likely, there is a definite trend in erage fishing power with time; older and inefficient ships or gear being replaced by ore powerful ones. To avoid this source of bias the effort should, as shown by Beverton d Parrish (1955), take into account the fishing power of each vessel, and be expressed a standardised form, e.g. in terms of hours' fishing of a standard vessel. Such ındardization has been used, sometimes in an incomplete form, in several fisheries, g. Thursby-Pelham (1939) corrected the figures for the catch per unit effort of plaice er the introduction of the Vigneron Dahl gear, reducing them by the factor of $\frac{1}{4}$, derived om the figure found by Bowman (1932) for catches of haddock. This is in effect expressing e effort always in terms of a pre-V.D. trawler, the power of a trawler with V.D. gear ing 25% greater. Gilis (e.g. 1952) has used the term horsepower-times-hours-fishing to tain a standardized form for the effort of Belgian herring trawlers.

Some of the difficulties arising from the differences in fishing power may be avoided dividing ships into various classes, e.g. by tonnage, in each of which the fishing power ay be presumed to be more nearly constant. This enables the catch per unit effort of any e class to give a more reliable index of density, but without knowing the relative fishing wer of each class, neither the total fishing effort, and hence the fishing mortality nerated nor the best combined index of density, can be readily determined. Such div- ons have been made in several fisheries, e.g. the Belgian herring trawling, Gilis (e.g. 1952), d the Georges Bank haddock (Rounsefell, 1948).

It is useful to note, as pointed out by Beverton and Holt, that it is not necessary so ıch to know the fishing power of each individual ship, as to find a factor readily termined from the specifications of the ship, which is on the average proportional to the hing power. This enables any important changes in the average fishing power of the fleet be detected and evaluated.

Though it has often been remarked that bigger ships catch more fish, for calculations to find, for all or most of a commercial fleet, the fishing power in the st sense defined above have seldom been made. Rather more often, the relative fishing po of two or three vessels have been determined experimentally, usually at least one of ships being a special research vessel. Such comparisons have been made between Engli Scottish, Dutch and Danish trawlers (Margetts, 1949a, Parrish 1949, Parrish 1951), English trawlers and seiners (Margetts 1949b).

Large scale evaluations of relative fishing power (in the strict sense) of individual sh have been made by Beverton and Holt for the English North Sea trawler fleet and to a les extent by Boerema (1950) for Dutch steam trawlers. Beverton and Holt showed that, t satisfactory degree, fishing power was proportional to gross tonnage for both steam a motor trawlers, the constant of proportionality for motor trawlers being 1·4 times that steam trawlers. Schaeffer (1953) has evaluated fishing power for the American Pacific tu fleet. Earlier corrections have been made for changes in fishing power, though not in strict sense defined here. Garstang (1900) expressed the effort of steam trawlers and lin in terms of sailing trawlers, on the basis of catch per year. Lee (1911) compared the ca of different species per ten hours fishing of various classes of ships (English sailing trawle and large and small steam trawlers and Dutch steam trawlers) in the same area during same month. As the catch per unit fishing time was based on the total activities of all sh of each class, she did not evaluate the fishing power of any individual ships, but determine the relative fishing power of the average ship of each class. Hickling (1946 working on the Milford Haven trawler fleet, did not calculate fishing power as such, performance. He defined performance as the catch per 100 hours fishing, and it th differs from fishing power in that the catches are not necessarily made at the same place a time. One other term may be defined; the fishing capacity, i.e. the gross catch of a ves over a period. Performance therefore takes into account the possible ability of some sh to go further afield and thus fish better grounds, while fishing capacity also includes ability of some ships to do more fishing during the year than others. In some cases, wh the available statistics of fishing time are poor, the performance or fishing capacity m provide the best key to fishing effort. For instance, if there is no information on ti spent fishing during the year, so that it has to be assumed constant, fishing capacity v give the best index of the real effort, while if the position of fishing is not record performance will be preferable. However, the time spent fishing during the year and fishing positions of a particular ship are quite likely to change from year to year, a thus change the ship's performance or fishing capacity. It is therefore preferable to fishing power throughout, together with adequate statistics of fishing time and fish position, as defined by Beverton and Parrish (1955).

In the present paper, the work of Beverton and Holt has been repeated on Lowest North Sea trawlers, at a time when more motor trawlers were fishing, in order to determ more exactly the relative fishing power, ton for ton, of motor and steam trawlers, and a to determine whether any other factor, e.g. horsepower, was closely related to fishing pow The methods were also applied to trawlers fishing to the south and west of Ireland, Iceland, in the Barents Sea, and for North Sea seiners. These calculations enabled a fish power, of varying accuracy, to be attached to some 450 vessels, comprising some 40% the English first-class demersal fleet. The relation of various factors, particularly gr tonnage, to fishing power have then been examined. In the last part of the paper the resu of the calculations have been applied to the English fishery at Iceland. These have enab revised and more accurate figures for the effort and catch per unit effort, and hence inc of density, to be obtained for the stocks of cod and other species at Iceland.

In comparative fishing experiments between a pair of ships, it has often been obser that the composition, by species or size of fish, of the catches of the two ships has not be the same, e.g. a seiner caught more plaice than a trawler but very much fewer sc (Margetts, 1949b); and while a Scottish research trawler outfished an English one haddock, the reverse was true for plaice, (Parrish, 1951). This may be interpreted meaning that the relative fishing power of the two ships is different for different species fish. Strictly, therefore, fishing power should be defined relative to one species of fish, even one size of that species. While the difference between trawls and seines represe

onstant effect, apparent also in the commercial statistics, the difference between the two wlers appeared to be a matter of design or rig of the gear, EXPLORER's gear being adapted rticularly for catching round-fish and SIR LANCELOT's for catching flat-fish. If they were mmercial trawlers they would probably have adapted their gear to the grounds and the h present; that is, they would tend to be both using the same gear on any one fishing ound. This is borne out by comparing a set of catches of commercial trawlers working e same grounds; these are usually remarkably similar in composition both by species, d by size, as judged by market categories, within a species. That is, the relative fishing wers on different species is the same. This does not imply that any one ship has the me fishing power for all species, or even for the same species on different grounds; . the constant α of equation (1) (page 5) may vary from species to species and from ound to ground, but is the same for all ships for any given fishing ground and species fish.

In the analysis, therefore, the relative fishing powers of trawlers and seiners have been orked out using catches of plaice alone, and also all demersal species taken together. trawler-trawler comparisons no account has been taken of species composition. Because ips are fishing ultimately for the monetary return, the value of the catch at first sale could e taken as a fair measure of the catch. It would unfortunately introduce another source of riation—market prices—into a set of data which are already quite variable enough, and e total weight caught has been adopted throughout this paper.

A word is necessary on the effects of skill of skippers and crews. Personal factors are own to be important in the profitability of ships: indeed, in the opinion of many trawler-wners the skipper's efficiency is the most important matter to which to pay attention. second important factor is equipment of instruments; and there are numerous other uses of variation in catch per day's absence. In the present analysis, a ship is considered that ship manned and equipped as she was during the period under review, and variations om time to time may be assumed to even out in the process of averaging so long as they e not correlated with the particular factors (e.g. tonnage) being considered. Although ata for particular ships form the basis of the enquiry, the ships will not be named, but will e given arbitrary serial numbers. It will not be possible to answer enquiries about rticular ships, but any general information not included in this paper will, if possible, be ade available to responsible enquirers.

CALCULATION OF FISHING POWER

THE BASIC information used in calculating the fishing power is provided by the 'D' form. ne of these is filled in for every landing by English first-class vessels. The information them includes the name of the ship, with its number and port of registration, the date d port of landing, the fishing ground, (where more than one ground has been visited, the e where most fishing was done is recorded in the main body of the form, and a note made of other grounds visited), the length of the trip in days, the number of hauls made, d their average duration, and hence the number of hours spent fishing, and finally the eight caught of each species of fish.

Essentially the major computational work involved in the present analysis consists of viding the total catch, either of all species, or of some species of particular interest, by the urs fishing to give the catch per unit time, and then dividing this catch per unit time some standard catch per unit time to give an estimate of the fishing power. The work n therefore be considerably simplified by using logarithms throughout. After calculating e logarithms of catch and hours fishing, the computation merely involves successive btractions. In practice, the calculations were only carried to two figures, as this is well thin the range of variance of the data, so the calculations could be made very quickly d easily.

Another major part of the computation involves picking out pairs or sets of ships whi have fished at the same time and place, in order then to compare their catches per un time. This may be conveniently done by tabulating the catch per unit time for ea individual trip in the form of Table 1. This gives the activities of a group of Engli trawlers on a single fishing ground to the south of Ireland in one month of 1951. T dashes give the extent of each trip, as given by the days absence and date of landing shov on the 'D' form, and the number is the logarithm of the catch in cwts. per ten hou fishing. For example, the first trip of vessel number 391 began on 23rd February a finished on 3rd March, with a log catch per unit time of 1·35, i.e. 22·4 cwt. per ten hou From this table ships fishing at the same time can be picked out at a glance, and t difference in their log catch per unit time, and hence their relative fishing powe calculated almost as quickly. For instance, comparing the first two vessels (numbers 3 and 392), their first trips overlap and the difference of the two figures is 0·02. This giv the second ship as being more powerful by a factor of $10^{0.02}$, i.e. by 5 per cent approximate The second trips of the two ships do not overlap, and so give no information on the relative fishing power.

The use of logarithms has also considerable theoretical advantages. The log tran formation has been used quite often for rather similar data; e.g. for catches of fish of o trawl haul by a research vessel (Parrish, 1951, Barnes and Bagenal, 1951, Taylor, 195 long-line catches (Murphy and Elliott, 1954) and for catches of a plankton net (e.g. Wins and Clarke, 1940). The log transformation is a considerable improvement towards stabiliz

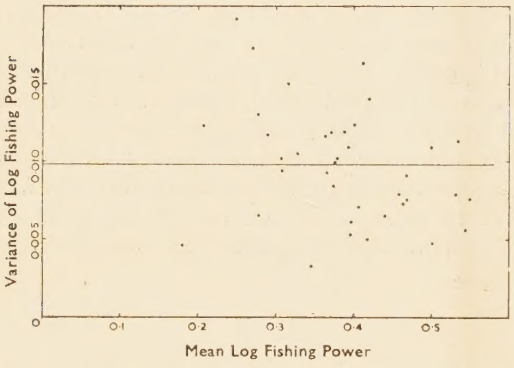


Fig. 1. *Relation between the mean and variance of the logarithm of the fishing power of North Sea trawlers, as estimated from successive trips. Showing approximately constant variance.*

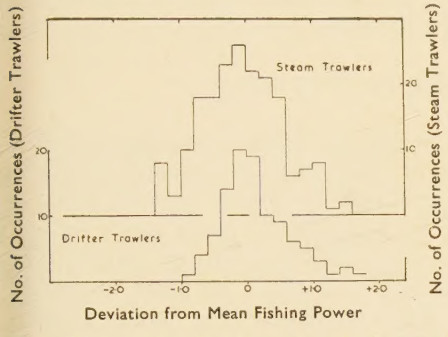
Fig. 2. *Relation between the mean a variance of the fishing power of Nor Sea trawlers as estimated from succe sive trips, showing marked correlati between variance and mean.*

the variance. This can be seen by inspection of Fig. 1 where the variance of the transform data is evidently independent of the mean, whereas in Fig. 2, showing the original data, f successive trips of particular ships, the variance is clearly correlated with the mean. Fro data of Beverton and Holt (in Press) shown in Table I the same independence is obtain when the data are of trips of different ships of about the same tonnage.

Table I: *Mean fishing power, and variance of log fishing power, for different tonnage classes North Sea trawlers*

Tonnage Class	81–100	–120	–140	–160	–180	–200	–220	–240	–260	–280
Number of ships	49	13	10	13	27	23	28	32	15	7
Variance (logs)	0·022	0·034	0·013	0·028	0·037	0·032	0·064	0·050	0·064	0·01
Mean fishing power	0·80	0·99	0·95	1·13	1·28	1·51	1·42	1·51	1·39	1·47

The transformed data also tends to be distributed normally, as is shown by Figs. 3 and 4. g. 3 gives the frequency distribution of the deviations from the mean of the tonnage-class estimates of fishing power from individual trips of Lowestoft drifter-trawlers (lower gure) and for the large Lowestoft North Sea steam trawlers (upper figure). The two have be given separately because of the unequal variance, the lesser spread for the smaller



ig. 3. *Frequency distribution of the deviaons from the mean of the estimated fishing wer of steam trawlers (upper figure) and ifter-trawlers (lower figure).*

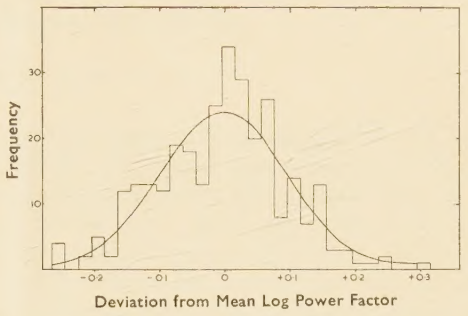


Fig. 4. *Frequency distribution, and fitted normal curve, of the deviations from the mean of the estimated log fishing power of North Sea trawlers.*

rifter trawlers being quite apparent. Fig. 4 gives the similar distribution for the garithmically transformed data; the data from all ships can now be combined because the ariance is now approximately constant. Allowing for the small numbers involved, none of ie histograms depart seriously from normality. A normal curve has been fitted in Fig. 4, id applying the χ^2 test to the grouped data gives $\chi^2 = 11{\cdot}96$, $n = 11$, $P = 0{\cdot}3$. That is, ie fit to the normal curve is as good as can be expected. Beverton and Holt (in press) have iowed that a rather similar log-normal distribution applied to the ratio fishing power : ross tonnage for individual steam trawlers.

It would be easy to demonstrate that the other criterion of Bartlett (1947) on the sefulness of transformations is met in the present instance, namely that major effects iould be independent and additive. This will be apparent from inspection of the iathematical form of the catch per unit of effort logarithmically transformed, which we iay now derive. Let us consider the catch from a particular trip. This will be given as the roduct of the fishing power of the boat, the length of time spent fishing, the density f fish at the time and place of fishing, possibly a factor relating to the 'vulnerability' of the sh, and finally a residual error, or random term. That is, in mathematical terms, we have or the ith boat, fishing in the jth position and period,

$$Y_{ij} = P_i \times t_{ij} \times D_j \times \alpha_j \times \varepsilon_{ij} \quad \ldots \qquad (1)$$

here

Y_{ij} = catch
P_i = fishing power
t_{ij} = time spent fishing
D_j = density of fish
α_j = vulnerability
ε_{ij} = random variable

aking logarithms, (1) becomes

$$\log Y_{ij} - \log t_{ij} = \log P_i + \log D_j \alpha_j + \log \varepsilon_{ij} \quad \ldots \quad \ldots \qquad (2)$$

hich may be rewritten as

$$d'_{ij} = P'_i + D'_j + \varepsilon'_{ij} \quad \ldots \quad \ldots \quad \ldots \qquad (3)$$

(cf. Winsor and Clarke (1940), p. 4)

where

$$d'_{ij} = \log d_{ij} = \log \text{(catch per unit time)}$$

$$= \log Y_{ij} - \log t_{ij}$$

$$P'_i = \log P_i$$

$$D'_j = \log D_j \alpha_j = \log \text{effective density} \quad .. \quad .. \quad .. \quad (4$$

$$\varepsilon'_{ij} = \log \varepsilon_{ij} = \text{random variable, mean zero.}$$

The fishing power of a vessel has been formally defined by reference to the catches of single standard vessel. Essentially the need is for some measure of the density of fish, an it is only because this measure is usually impossible to obtain directly that the catch of standard vessel has been used. There is therefore no necessity to use a single vessel a standard, and in practice it is often easier to use as standard a group of vessels, whos relative fishing powers are known. Even some different gear could be taken as standar providing this latter can be assumed to give a satisfactory measure of the density of fish.

Consideration of (3) shows that it is in a suitable form for carrying out an analysis c variance on the catches of a group of ships. The requirement for this to be done is simpl that a group of ships should exist which have fished all together at a number of times. Th requirement was virtually fulfilled by a group of 14 distant-water trawlers fishing a Skolpen Bank in the Barents Sea towards the end of 1951. All of them fished there durin overlapping times during three periods, viz.: in the first fortnight of October, the last wee of October and the first week of November, and the last week of November and the fir week of December. The actual times of fishing were estimated from a knowledge of th day of landing, the duration of the trip, and the average steaming time from the Humbe to the Barents Sea. The logarithms of the weight caught (in cwts.) of all species per hou fishing for each trip is shown in Table 2. The resulting analysis of variance is shown i Table II below.

Table II: *Analysis of variance of log catch per hours fishing at Skolpen Bank*

	Degrees of Freedom	Sum of Squares	Mean Square	
Ships	13	0·4385	0·03373	$P < 0{\cdot}01$
Periods	2	0·1299	0·06495	$P < 0{\cdot}01$
Residual	26	0·2184	0·00840	
Total	41	0·7868		

This shows that there have been significant changes in the density of fish in the regio during the period, as well as significant differences in fishing power between ships. Thes latter will be discussed later in the paper. For the present, it is enough to note that th smallness of the residual variance allows us to take as an estimate of the relative log fishin power of a vessel, the mean of its log catch per unit fishing time during each of the thre periods. We thus have a standard frame of reference against which the fishing power c any other vessel can be assessed. To do this we first note that (3) can be written in the form

$$D'_j = d'_{ij} - P'_i - \varepsilon'_{ij} \quad .. \quad .. \quad .. \quad (5$$

and hence if the ith ship is one of the standard group, an estimate of the density of fish a the jth occasion is

$$D'_j = d'_{ij} - P'_i \quad .. \quad .. \quad .. \quad .. \quad (6$$

ombining all estimates for all standard vessels fishing at that occasion (= n in number, y) we have

$$\bar{D}'_j = \frac{1}{n} \sum (d'_{ij} - P'_i) \quad .. \quad .. \quad .. \quad (7)$$

e summation being taken over all the relevant standard vessels. Hence, the estimated g fishing power of the kth boat, fishing at that occasion is, from (4)

$$P'_k = d'_{kj} - \bar{D}'_j \quad .. \quad .. \quad .. \quad .. \quad (8)$$

The fishing times of the standard trawlers, each of which did three trips in the period id-September-mid-December, overlap during the three intervals mentioned above, but is overlap is not complete. Thus, though an individual trip lasted only ten days to a rtnight on the fishing grounds, the length of time during which one or more of the andard ships was fishing at Skolpen Bank was more nearly three weeks for each of the ree intervals, i.e. altogether for some ten weeks of the whole three month period, rather an only six weeks. In fact, the only times when one of the standard vessels was not esent were a gap of about a week between the last trip in the first period, and the earliest ip of the second period, and a similar gap between the second and third periods. We then ave, from (7), and some interpolation, an index of log-density at Skolpen Bank from mid-eptember to mid-December. The interpolation for the missing weeks is not likely to use great inaccuracy, as the trip of any vessel fishing during the gap is likely to overlap one end or the other with a period in which the index of density has been obtained rectly. The density is in purely arbitrary units, corresponding to the arbitrary choice the unit of log fishing power. The fishing power of any other trawler fishing at Skolpen ank during the period September-December, 1951, can now be obtained directly from (8), sing the index of density for the mid-point of the trip. This has been done for some 50 trawlers.

The requirement for the group of standard ships, that they should, on several occasions, ave fished all together, is quite a severe one, and it is not always possible to find such a roup containing a reasonable number of ships, which have fished all together on more than limited number of occasions. However, the relative fishing power of a group of ships can e determined under rather less stringent conditions. These are that each ship of the group ould at least once have fished at the same time and place as each of the others. This does ot imply that the ships of the group have fished all together even once. The relative shing power, i.e. the difference in their log catch per unit time, for every pair of ships an then be calculated. This is most easily done from an array such as Table 1. Generally, here will be several estimates of the relative fishing power, one derived from each occasion hen the two ships fished together. Taking the arithmetic mean of the differences in log atch per unit time as the best combined estimate, this may be entered in a table such as hat shown in skeleton form as Table 3. In this table calculated for a group of Lowestoft awlers, each row and column corresponds to one of the standard ships; the entry in the h row and jth column which we will denote by x_{ij}, is equal to the difference in log fishing ower between the ith and jth ships, 0·50 being added to avoid negative values. The entry the jth row and ith column, x_{ji}, is, of course, equal to $1 - x_{ij}$. For example in Table 3, $_{12}$, the second entry in the first row is 0·465, and $x_{21} = 0{\cdot}535$. Subtracting 0·5 we have that he second ship outfished the first by an amount $10^{0{\cdot}035}$, i.e. by about 8 per cent. The actual umber of comparisons for each pair of boats used in calculating Table 5 varied between 1 for only 5 out of the 870 pairs) up to 14.

From (3) we have, for one pair of trips, made on the jth occasion

$$x_{ik} = d'_{ij} - d'_{kj} + 0{\cdot}5$$

$$= P'_i - P'_j + \varepsilon'_{ij} - \varepsilon'_{kj} + 0{\cdot}5$$

$$\therefore \text{Expectation of } x_{ik} = P'_i - P'_j + 0{\cdot}5 \quad .. \quad .. \quad .. \quad .. \quad (9)$$

Summing along the row, for all n ships, we have

$$E\left(\sum_{k=1}^{n} x_{ik}\right) = \sum_{k=1}^{n} (P'_i - P'_k + 0{\cdot}5) \text{ putting } x_{ii} \text{ arbitrarily equal to } 0{\cdot}$$

$$= n\,P'_i - \sum_k P'_k + 0{\cdot}5n.$$

$$\therefore \text{ Expectation } \left(\frac{1}{n}\sum_k x_{ik}\right) = P'_i - \frac{1}{n}\sum_k P'_k + 0{\cdot}5 \qquad \ldots \quad \ldots \quad \ldots \quad (1$$

In (10), $1/n \sum P'_k - 0{\cdot}5$ is a constant, so that $1/n \sum x_{ik}$ may be taken as an estima of P'_i, the log fishing power. The constant term only alters the value of the estimate fishing power by a constant factor, and because the fishing power as considered here is on a relative measure, the constant term may be ignored. The estimated fishing powers th obtained are shown on the right hand column of Table 3.

Besides the Lowestoft North Sea fleet, the relative fishing power for a group of standa trawlers fishing at Iceland was obtained in the same manner. For trawlers fishing out Milford Haven, there was a very marked division in the areas fished between the sm drifter-trawlers, which fished in the Bristol Channel and along the south-east coast Ireland, and the bigger trawlers, fishing to the west and south-west of Ireland. It w impossible to find a single group of trawlers, whose relative fishing powers could calculated by the above method, and which would cover adequately the whole activiti of the Milford Haven fleet. Two standard groups were therefore taken, one mainly drifter-trawlers, and one of the larger 'castles'. The estimates of log density, and of lo fishing power, on these two scales, and of course on the other scales used, will be differe but will only differ by a constant. Once this constant for any pair of scales has be determined with sufficient accuracy, then the two scales can be at once combined.

When the relative fishing powers of the standard ships have been established, then, f any area in which any standard ships have been fishing, the estimated log density from o trip can be obtained, from (6). The mean log density for each short interval may calculated, in the same way as for Skolpen Bank from (7). Alternatively, the individu estimates may be plotted individually, and a smooth curve drawn through them by han Examples of such curves, with the points to which they were fitted, are shown in Figs. 6 and 7. These are for the statistical rectangles YY51 (Trevose Ground, in the Brist

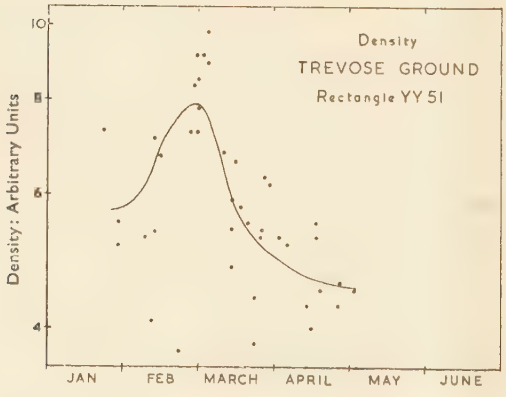


Fig. 5. *Fluctuations in the estimated density, i.e. catch per standard fishing effort on the Trevose Grounds (rectangle YY51) during 1951; showing the estimates from single trips of the standard ships, and the curve fitted by eye. Logarithmic scale*

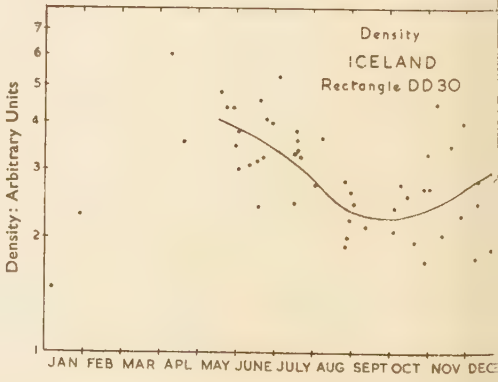


Fig. 6. *Fluctuations in the estimated densit i.e. catch per standard fishing effort at N.V Iceland (rectangle DD30) in 1951; showi the estimates from single trips of the standa ships, and the curve fitted by eye. Logarithm scale.*

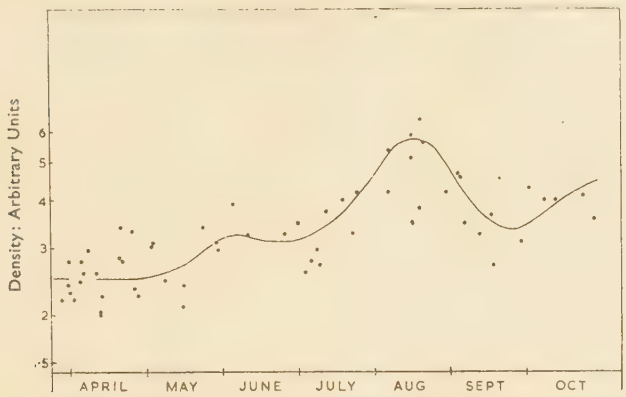


Fig.7. *Fluctuations in the estimated density, i.e. catch per standard fishing effort at Cleaver Bank (rectangle H7) in* 1951*; showing the estimates from single trips of the standard ships, and the curve fitted by eye. Logarithmic scale.*

hannel), DD30 (N.W. Iceland), and H7 (Central North Sea), respectively. The estimated g density is easily read from the graph, and from (8), a log fishing power may be at once btained for each trip in the area by any non-standard vessel.

In the areas visited by only a few standard ships, there may not be enough points to raw a reasonable curve, and the fishing power of the non-standard ships may be better btained by direct comparison with such of the standard ships which have been fishing at ne same time. This may be readily done from the array of Table 1. The method is lustrated in Table 4. Of the ten ships, four belong to the standard group, and their log- shing powers are given in the second column. The main body of the table is merely a epeat of the data of Table 1, but underneath the log catch per hour of the standard ships s given (in brackets) the estimated log density during that trip, i.e. log catch per hour inus log fishing power. The estimated log fishing power for any trip of a non-standard hip may be calculated by subtracting the mean log density of all overlapping trips by tandard ships, from the log catch per hour. This is given in the right hand column. For xample, the last trip of the first ship (No. 391), overlaps with only one standard trip, with log density of 0·73; thus the log fishing power of vessel No. 391 estimated from the esults of her third trip is $1{\cdot}22 - 0{\cdot}73 = 0{\cdot}49$. Her first trip overlaps with three standard rips, giving an estimated log fishing power of $1{\cdot}35 - 1/3\,(0{\cdot}99 + 0{\cdot}95 + 0{\cdot}93) = 0{\cdot}39$ pproximately.

By these methods the fishing power of trawlers fishing at Iceland, and of the Lowestoft North Sea fleet have been calculated. For the Milford Haven fleet two sets of power factors, ne containing all the small drifter-trawlers, and the other, the large 'castles' have been btained. There are some fourteen medium sized trawlers with fishing powers on both cales; a comparison of the two power factors for the same ship enables the two scales to be ombined. Table 5 gives, for these fourteen ships, the log fishing power for each ship on he two scales, and the difference between them. The mean difference is 0·23, showing hat unit fishing power on the 'castle' scale is $10^{0.23} = 1{\cdot}7$ times as great as unit fishing ower on the drifter-trawler scale. Subtracting 0·23 from all the log-fishing powers on the D/T scale therefore brings all the fishing powers on to the same scale.

Finally, the fishing powers of some English North Sea seiners have been calculated on he basis of catch per day at sea.* For the calculations the catch of steam trawlers fishing the ame grounds were used to provide a standard of reference for the density of fish. Following he results of Beverton and Holt (in press), it was assumed that the fishing power per ton f North Sea trawlers was constant, and the unit of density used was the catch per steam rawler-ton-day. The log fishing power of a seiner as estimated from one trip was therefore

*These calculations were originally made from the point of view of possible regulation of effort. The unit of ishing time used was therefore one which could be measured and hence enforced by an independent authority, which ruled out hours fishing; days at sea was therefore used as a measure of fishing time.

the difference between the log catch, and the mean log density, as given above, as estimate from the catches of all steam trawlers fishing the same area at the same time. Most of thes comparisons were made from trips to the Off-grounds to the N.E. of the Humber As mentioned earlier the comparisons were made separately for plaice and for all demersa species taken together. Unlike the previous estimates of fishing power, the units of whic were purely relative, these units are meaningful, being the tonnage of the steam trawle having the same fishing power, in terms of catch per day. This seiner-trawler compariso may be approximately converted into terms of catch per hour by comparing the total day absence and hours fishing in the central North Sea, by steam trawlers and seiners in 1951 given in Table III. This shows that, per days absence from port, steam trawlers spent on a average 1·91 times as many hours fishing as a seiner. Thus, we may deduce that b multiplying the figures based on catch per day by a factor of 1·91, they may be approxi mately converted to fishing power in terms of catch per hour.

Table III: *Relation between measures of fishing time for seiners and steam trawlers fishing in th central North Sea*, 1951

	Days absence	Hours fishing	Hours per day	A/B
Trawlers	40,045	535,592	13·37 (A)	1·91
Seiners	12,233	85,671	7·00 (B)	

Before analysing the fishing power data, the degree of variance encountered may b examined. Assuming that the catches from the standard ships determined the density o fish exactly, the variance of the fishing power of some other vessel, as estimated from on trip, will be the same as the variance of the catch per unit fishing time on a fixed densit of fish. For a single haul, Parrish (1951), using the log-transformation, found a residua variance of 0·0222 for the catch of all species in one two-hour haul. In the average commer cial trip some fifty hauls may be made, so that the smallest variance between trips would b 0·0222 divided by $\sqrt{50}$, i.e. about 0·003, if the only source of variance was the haul-to-hau variation. The observed residual trip-to-trip variances were:

Skolpen Bank standard ships:	0·00840
Lowestoft motor trawlers:	0·01026
Lowestoft steam trawlers:	0·00956
Milford Haven drifter-trawlers:	0·01062
Milford Haven 'castles':	0·01103

The agreement within this set of figures is very good, but they are all greater than th predicted variance. This is only to be expected, for Parrish's data were obtained from carefully controlled experiment with two research vessels fishing side by side on as far a possible, the same ground. The present data are from catches reported in the same statistica rectangle, so that two catches may have been 30 miles apart, or even more, as often all th fishing during one trip is not made on the same ground, or in the same rectangle. The ground and rectangle recorded is that in which most fishing occurred. The difference between the observed and predicted trip variance is really not very great, the trip variances being in every case less than half the variance from a research vessel haul, and we may conclude that the observed variance is due mainly to random haul-to-haul variations.

An implicit assumption in the calculations has been that the relative fishing power o two ships is independent of the ground being worked. That is, if one ship is twice as powerful as another on one ground, it will be twice as powerful as the other when the two ships are fishing any other ground. This seems generally a reasonable assumption for any one type of gear, taking averages over several ships, though it is possible, for instance, that large ships outfish small ships to a relatively greater extent when fishing on rough grounds. For a pair of ships it is of course probable that each skipper may know one ground or another particularly well. Two distinct types of gear, e.g. trawls and seines, do indeed

erform differently on different types of bottom, the rougher the bottom the less well does e seine perform relative to a trawl. In Table IV below an analysis of variance has been rried out on the log fishing power estimated from individual trips by Lowestoft motor awlers.

Table IV: *Analysis of variance of log fishing power of Lowestoft motor trawlers*

Source of Variation		D.F.	Sum of sq.	Mean sq.
Between ships		13	1·23391	0·09492
Within Ships	Between areas	45	0·52775	0·01173
	Within areas	124	1·20563	0·00972
Total		182	2·96729	

his table shows, as could be expected, that there is considerable difference between ships. he between-areas mean square is not significant, showing no definite evidence that ships o perform relatively differently in different areas. In the absence of other evidence, it is robably justifiable for our present purpose to continue with the assumption that the elative fishing power of two ships is independent of the area in which the comparison is ıade.

THE RELATION OF FISHING POWER OF TRAWLERS TO VESSEL CHARACTERISTICS

THE TRUE power of a fishing unit—the vessel and its gear—must depend on a large ariety of factors. Margetts (1949a) concluded that while, other things being equal, the atches of plaice were proportional to the distance between otter boards, quite minor hanges in the rigging of the trawl made appreciable differences to the catch. However ve are not here concerned with the latter causes of differences in fishing power, but only ı obtaining a correct measure of fishing power which will be without bias for all types of essel. We will assume here that any commercial fishing vessel will rig its gear in the most fficient manner for the ground being fished, and again that each trawler will carry as big trawl as it can use efficiently. These assumptions seem reasonable, though the introduction f new inventions, such as the Vigneron-Dahl gear, may invalidate the first for comparisons ver periods of years. Also it is likely that a good skipper will adapt the rigging of his gear o the ground, and the species of fish present, more quickly and efficiently than a poor kipper. However, the main difference in fishing power between two trawlers would appear o lie in the difference in the size of trawl they can use and the speed at which it can be owed, which depend on the size of ship and power of engines. Of the possible measures of he size of ship—gross tonnage, nett tonnage, length, etc., gross tonnage has been used oth by Hickling (1946a) and Beverton and Holt (in press), and the relation between this nd fishing power will be considered first. We will consider the following groups of rawlers:—Lowestoft steam trawlers, Lowestoft motor trawlers, Milford Haven trawlers, rawlers fishing at Iceland, all trawlers fishing at Skolpen Bank, and the standard group of rawlers fishing at Skolpen Bank. For the last group we may calculate the regression of log ıshing power on log gross tonnage; that is, postulating a relation of the form

$$\log P = \log a + b \log T$$

$$\text{i.e. } P = aT^b \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11)$$

where T = gross tonnage and a, b are constants

which will preserve the statistical advantages of the log-transformation mentioned earlie
For the other groups of trawlers the fishing power of the various ships will have bee
estimated with varying accuracy, depending chiefly on the number of trips used in th
analysis. The main advantage, equality of variance, of the log transformation, is therefo
lost, and it is not much less desirable from the statistical viewpoint to consider th
regression of fishing power on gross tonnage; i.e. postulating a relation of the form

$$P = a' + b'T \quad .. \quad .. \quad .. \quad .. \quad (1$$

where a', b' are constants.

This has the advantage of being more readily interpretable. It may be noted th
equations 11 and 12 become the same if $b = 1$ and $a' = 0$ and then fishing power is direct
proportional to gross tonnage. For the Lowestoft trawlers the regression is fitted to th
data of individual ships, but for the other three groups of trawlers it has been fitted to th
central values of tonnage classes. These latter were determined, as was done by Beverto
and Holt, as the antilog of the mean log fishing power of all ships in the tonnage-clas

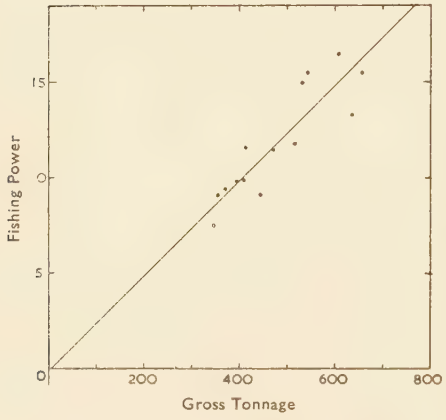


Fig.8. *Regression of fishing power on gross tonnage for the* 14 *standard trawlers fishing at Skolpen Bank.*

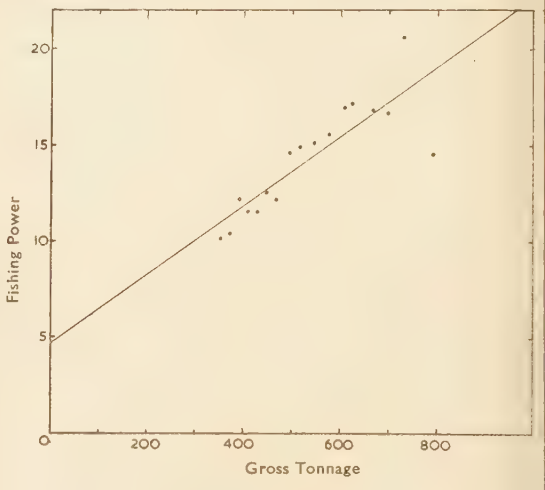


Fig.9. *Regression of fishing power on gro tonnage for all steam trawlers fishing at Skolp Bank, in October-December,* 1951. *Points a the means of tonnage groups.*

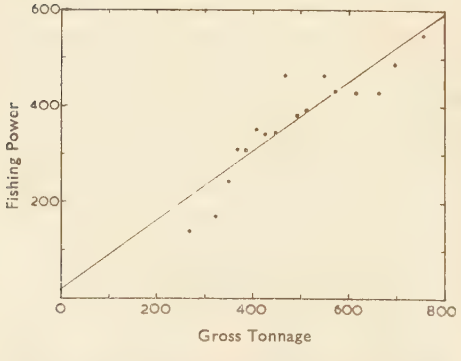


Fig.10. *Regression of fishing power on gross tonnage for steam trawlers fishing at Iceland in* 1951. *Points are means of tonnage groups.*

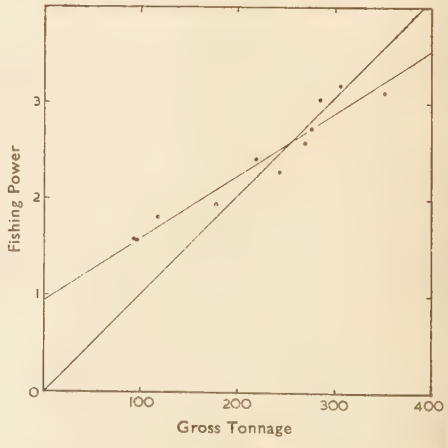
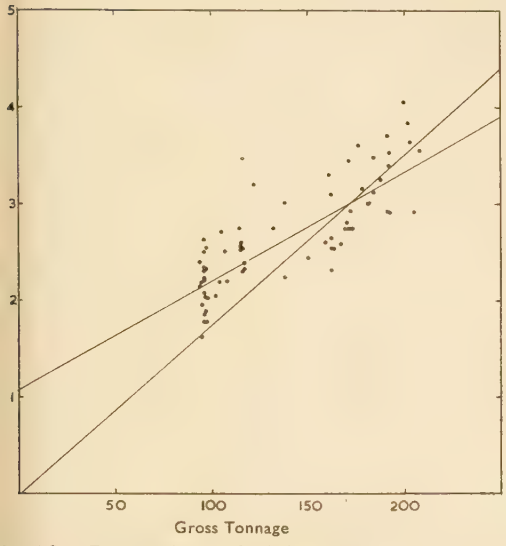


Fig.11. *Regression of fishing power on gro tonnage for steam trawlers fishing out Milford Haven in* 1951. *Points are means tonnage groups. Showing also the best fitti proportional line.*



ig. 12. *Regression of fishing power on gross nnage for steam trawlers fishing from Lowestoft* 1951. *Showing also the best fitting proporonal line.*

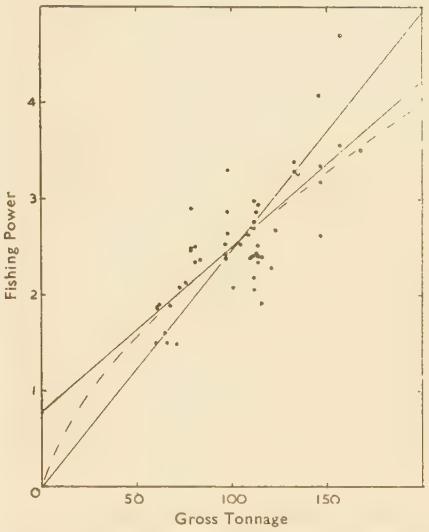


Fig. 13. *Regression of fishing power on gross tonnage for motor trawlers fishing from Lowestoft in* 1951. *Showing linear regression (full line) and log-log regression (broken line), and also the best fitting proportional line.*

e. as the geometric mean of the individual fishing powers. The regressions, and the points) which they were fitted, are shown in Figs. 8-13. In Fig. 13, for Lowestoft motor trawlers, ıe regression derived from (11) is shown (broken line) as well as the direct regression of shing power on gross tonnage (full line). Over the observed range of tonnage the two lines re very nearly identical, the log-log regression falling slightly below the other, due to ıe mathematical fact that the geometric mean is always less than the arithmetic mean. ecause the data, except for the standard ships at Skolpen Bank, do not fulfil the strict tatistical requirements, the regressions obtained, though providing a good picture of the elation between fishing power and gross tonnage, cannot strictly be used for tests of gnificance. However a cursory examination of the lines and the points they are fitted to ıows that the regressions are obviously significant without recourse to such tests.

The linear regressions obtained are, for steam trawlers,

$$P_1 = 0{\cdot}00655\ T + 0{\cdot}9387 \quad \text{(Milford Haven)} \quad \ldots\ (13)$$

$$P_2 = 0{\cdot}715\ T + 17{\cdot}97 \quad \text{(Iceland)} \quad \ldots\ (14)$$

$$P_3 = 0{\cdot}0180\ T + 4{\cdot}659 \quad \text{(Skolpen Bank)} \quad \ldots\ (15)$$

$$P_4 = 0{\cdot}01129\ T + 1{\cdot}073 \quad \text{(Lowestoft)} \quad \ldots\ (16)$$

Before discussing the implications, or statistical significance of these results, two points ıat might destroy their real significance should be mentioned. First, at least among the istant water (Iceland and Barents Sea) vessels, the larger ships are also the newest, so that ıe observed regression could be merely an effect of age. Secondly, it is possible that the est skippers go in the bigger ships, so that the regression merely expresses the skippers' ‹ill. The magnitude of the first effect may be seen from Fig. 14, in which the gross tonnage s plotted against the year of building for the ships for which power factors at Iceland were etermined. For convenience only one ship in three has been plotted in the diagram. That shing power is actually more nearly related to gross tonnage than age may be shown by ividing up the ships by age and tonnage classes. Within each tonnage class a year of uilding was chosen, appropriate to the particular tonnage group (see Table V), so as to ivide the ships into approximately equal groups of old and new ships, and hence the mean shing powers of old and new ships may be compared; similarly within each age-class ıe fishing powers of large and small ships may be compared. The results are given in 'ables V and VI below.

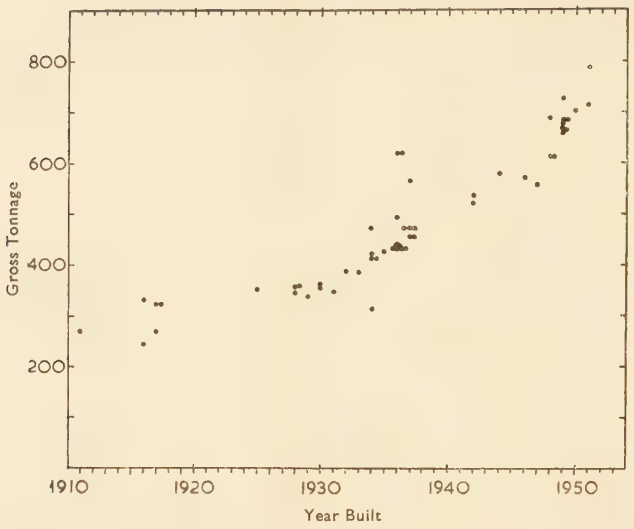


Fig. 14. *Gross tonnage of trawlers fishing at Iceland in* 1951, *plotted against the date of construction. To show the increasing size of new construction, and thence the correlation between age and tonnage.*

Table V: *Mean log power factors of old and new ships within each tonnage class, fishing a Iceland* 1951

Tonnage class	Dividing Year of Building	Log Power Factor (Old Ships)	(New Ships)	Difference New − Old
< 300	1920	0·19	0·10	− 0·09
300 – 329	1920	0·21	0·27	0·06
330 – 359	1929	0·37	0·44	0·07
360 – 379	1929	0·51	0·49	− 0·02
380 – 399	1934	0·62	0·40	− 0·22
400 – 419	1932	0·54	0·55	0·01
420 – 439	1934	0·60	0·51	− 0·09
440 – 459	1936	0·51	0·63	0·12
460 – 479	1936	0·77	0·60	− 0·17
480 – 499	1936	0·61	0·54	− 0·07
500 – 529	1939	0·72	0·43	− 0·29
530 – 559	1945	0·70	0·66	− 0·04
560 – 599	1945	0·65	0·61	− 0·04
600 – 639	1945	0·60	0·68	0·08
640 – 679	1949	0·64	0·60	− 0·04
680 – 719	1949	0·70	0·68	− 0·02
> 720	1949	0·69	0·78	0·09

Table VI: *Mean log power factors of large and small ships of each age-class, fishing at Iceland* 1951

Year Built	Dividing Tonnage	Log Power Factor		Difference Large-Small
		Small Ships	Large Ships	
Pre 1920	300	0·15	0·23	0·08
1920 – 9	360	0·38	0·51	0·13
1930 – 2	380	0·46	0·58	0·12
1933 – 4	420	0·53	0·64	0·11
1935 – 6	460	0·52	0·64	0·12
1937 – 9	480	0·61	0·61	0
1940 – 2	500	0·42	0·60	0·18
1943 – 5	530	0·38	0·68	0·30
1946 – 7	530	0·51	0·55	0·04
1948 – 9	640	0·72	0·67	– 0·05
1950 – 51	720	0·65	0·78	0·13

hese two tables taken together seem to leave little doubt that for two ships of the same ;e, the larger has, on the average, the higher fishing power, but that two ships of the same nnage will, on the average, have the same fishing power whatever their ages. In fact able V might if anything be held to suggest that the older ship would be more powerful, ough the difference is not significant. These facts may also give some evidence that a stematic difference in the skill of the skippers is not, at least wholly, responsible for the)served regression of fishing power on tonnage. If a skilled skipper did prefer to go in a rger ship, two reasons are likely; the ship has a higher fishing power, and thus will give gher earnings, or it is more reliable and comfortable. If there were no connection between shing power and tonnage, the first consideration would not apply; in fact because of gher expenses the larger ships would be less attractive, and it seems probable that the cond would apply with equal force to make the top skippers prefer the newer ships. hat is, we would expect at least as close a connection between age and observed fishing)wer, as between tonnage and observed fishing power. We may therefore deduce that the)served regression is not entirely due to the larger ships having the better skippers. remains possible that the true relation between fishing power and tonnage is less onounced than that observed, but is accentuated by the better skippers going in the more)werful, and hence larger, ships.

The fact that old and new ships have, for a given tonnage, the same fishing power, has plications in the analysis of fishing effort data for past years. Apart from changes in gear, id additional equipment—radar, echo-sounder, etc.—the fishing power of a ship can ardly be expected to increase with age, nor is it likely that at the same age the ships built rlier were, ton for ton, more powerful than those built more recently. Therefore, from the sults of Tables V and VI, it follows that the fishing power of a ship does not decrease ith age, and that for a given tonnage all ships have on the average the same fishing power gardless of their age or date of construction. This is not to say that ships of modern)nstruction do not have advantages in better speed, lower overheads, better accommo- ation, etc., or that a ship now does not have a greater effective fishing power than one of ie same tonnage had twenty years ago by virtue of improvements in gear, or in auxiliary quipment such as radar or echo-sounder. However, after making due allowance for known anges in gear e.g. Vigneron Dahl, it is probable that a medium or large trawler now enerates the same effort per hour as one of the same size did twenty years ago.

Of the six regressions considered, the only one suitable for strict statistical analysis that for the 14 standard ships at Skolpen Bank. For this set of ships we can now sub-divic the analysis of variance of Table II, dividing the effect 'ships' between that due to th regression of log fishing power on log tonnage (with 1 degree of freedom), and a residu variation about the regression line (with 12 degrees of freedom). This is shown in Table VI below.

Table VII: *Analysis of variance of log catch per hour of standard ships fishing at Skolpen Bank*

	D.F.	Sum of Sq.	Mean Sq.
Ships (Tonnage Regression)	1	0·3519	0·3519
Ships (Residual)	12	0·0867	0·0072
Trips	2	0·1299	0·0650
Residual	26	0·2184	0·0084
Total	41	0·7869	

The residual variance for ships is now actually smaller than the final residual varianc Thus the observed differences in fishing power between ships have been fully accounte for by the regression on gross tonnage. Such deviations as there are from the regressic line are such as would be expected from the apparently random variation in observe fishing power between trips by the same ship.

The residual variance about the regression line may also be compared with know random variations for the log-log regression for Lowestoft motor trawlers. The residu variance is 0·0046, while the variance of the log fishing power of one ship, as estimate from different trips, is 0·01026. The points to which the regression is fitted are the mea of between 1 and 20 trips,—say an average of 9 trips, so that their variance would b reduced to $\frac{1}{9}$ of that of one trip. The two figures are therefore in fair accord, and we ca again conclude that the deviations of the observed fishing power of a ship from th predicted from a knowledge of its tonnage may, to a large extent, be accounted for b random trip-to-trip variations.

For the ships working to the south and west of Ireland a similar conclusion may b reached from a different standpoint. Here it is possible to select two groups of trawle very much of the same tonnage:—10 'castles' of between 274 and 277 gross tons, an 16 small drifter-trawlers of between 94 and 97 gross tons. For each group an analysis variance of the estimated log fishing power from one trip has been calculated. These a given in Table VIII below.

Table VIII: *Analysis of variance of log fishing power, estimated from trips by 'castles' and drifter-trawlers*

	Castles			Drifter Trawlers		
	D.F.	Sum of Sq.	Mean Sq.	D.F.	Sum of Sq.	Mean Sq.
Within Ships	57	0·36456	0·00640	91	0·97707	0·01074
Between Ships	9	0·09926	0·01103	15	0·15632	0·01042
Total	66	0·46382		106	1·13339	
Variance Ratios	1·72	$P \simeq 0{\cdot}1$			0·97	

For the smaller drifter-trawlers this shows that the data contain no evidence that or ship is actually more powerful than another. For the group of larger ships the betwee

ips variance is just significantly greater than the within ships variance, but the difference not very great, again suggesting that the differences between ships is not very great. esides being of the same tonnage the ships in each group, while not exactly sister ships, e very much alike in other details—date of construction, length, nominal horsepower, etc. hus the absence of differences proves not so much that gross tonnage alone, but the vessel aracteristics generally, are sufficient to determine closely the observed fishing power of a ip. Similarly, in the regressions for the standard Barents Sea vessels and the Lowestoft otor trawlers, the analyses carried out, while they show that variation in fishing power er and above those determined by tonnage are small, do not preclude that some other ctor, closely related to gross tonnage, may not give a closer or more convenient index of shing power.

As remarked by Beverton and Holt a factor, e.g. length or gross tonnage, will be most nvenient as an index of fishing power if it is proportional to the fishing power. Then the shing power per foot, or per ton will be constant for all sizes of ship. The length or tonnage ill be direct measures of fishing power, and the foot-hour, ton-hour, or ton-day measures f fishing effort. If no such convenient index is found it may be necessary to seek arbitrary nits for fishing power, and hence fishing effort, with the disadvantage that they are bound be somewhat nebulous and not easily comprehended.

Examination of Figs. 8-13 shows that in two the relation between tonnage and fishing ower appears almost proportional. These are the standard ships at Skolpen Bank (Fig. 8), nd all ships at Iceland (Fig. 10). For the former, the parameter b of (11) has a value 1·0126, ith a standard deviation of 0·145, and for the latter the parameter a' of (12) has a value 7·97, with a standard deviation of 44·6. Thus neither departs significantly from roportionality, which requires that $b = 1$ or $a' = 0$. Taking all ships at Skolpen Bank ives a line departing considerably from proportionality. The departure is statistically ignificant, but depends essentially on the value for the largest tonnage class, as may be een from Fig. 9. Ignoring ships over 750 tons, both the standard group, and all ships ogether exhibit a proportional relation between tonnage and fishing power, and we may onclude that for the English distant water fleet, up to 750 tons, gross tonnage provides n adequate index of fishing power.

The other three graphs, for Lowestoft steam and motor trawlers, and for Milford Haven team trawlers, all exhibit regressions departing significantly from proportionality. In each ase the smaller ships are ton for ton the more powerful, i.e. the regression line passes above he origin. The various regression lines may be conveniently presented on one graph, and he various scales of fishing power combined by making them coincide at one point, which as been taken as a steam trawler of 300 gross tons. The regression lines then become

$$P'_1 = 0{\cdot}524\,T + 75{\cdot}1 \quad \text{(Milford Haven)} \quad \ldots\ (17)$$

$$P_2 = 0{\cdot}715\,T + 18{\cdot}0 \quad \text{(Iceland)} \quad \ldots\ (14)$$

$$P'_4 = 0{\cdot}588\,T + 55{\cdot}9 \quad \text{(Lowestoft steam)} \quad \ldots\ (18)$$

$$P'_5 = 0{\cdot}897\,T + 40{\cdot}3 \quad \text{(Lowestoft motor)} \quad \ldots\ (19)$$

nd these are plotted in Fig. 15. In this figure the regression lines over the range of tonnage ctually observed are shown as full lines, the rest being broken. It will be seen that taken ogether the lines give a consistent but non-linear relation between gross tonnage and ishing power of steam trawlers over a range 95-750 gross tons. In Table 6 the range of ariation of fishing power and fishing power per ton within each group of trawlers is given, ncluding for comparison the group of North Sea steam trawlers investigated by Beverton nd Holt. The fishing power and fishing power per ton has been calculated from the egressions for the extreme sizes in each group, and the tables show the ratio of both bsolute and relative fishing powers for the two sizes. For the Iceland trawlers the range in ishing power is nearly 200 per cent, but for fishing power per ton only 7 per cent. Thus ishing power per ton may for this group be taken as constant, and the product gross onnage × hours fishing used as a consistent measure of fishing effort. For the other groups, hough fishing power per ton has a smaller range than absolute fishing power, it is not onstant. Thus for these ships 'ton-hours' is not an entirely satisfactory measure of fishing ffort, though a better one than the plain number of hours fishing.

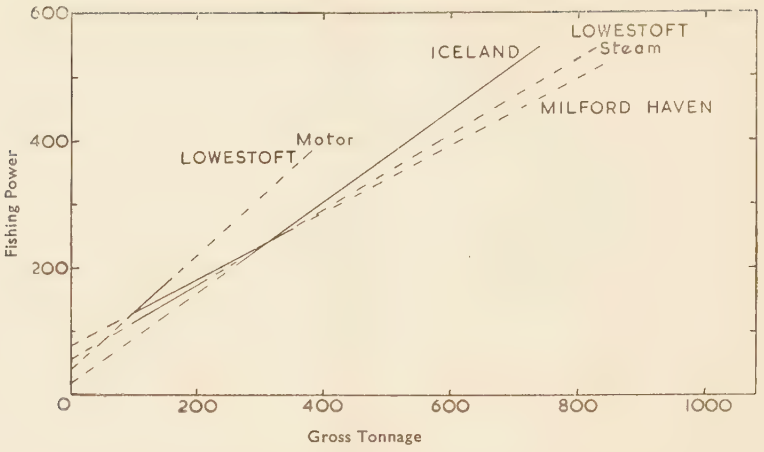


Fig. 15. *Regressions of fishing power on gross tonnage for different groups of trawlers shown on a combined scale. Whole lines denote the range of tonnage actually occurring within each group of trawlers.*

As may be seen from Fig. 15, motor trawlers appear to have a greater fishing power tha steam trawlers of the same tonnage. This has been remarked by Beverton and Holt (in press and on the assumption that within each class the fishing power was proportional to gros tonnage, they found that motor trawlers were 1·4 times as powerful as steam trawlers On the present data, in which the fishing power is not quite proportional to gross tonnage this factor relating steam to motor trawlers is not quite the same at all tonnages. At 95 ton (the smallest steam trawler), a steam trawler has a fishing power on the combined scale o 111·8, and a motor trawler 125·5, a ratio of 1·12,and at 160 tons (the largest motor trawler the figures are 150 and 183·8 respectively, giving a ratio of 1·22. These figures seem t differ considerably from Beverton and Holt's. However, their figure is based on proportional relationship, and hence represents effectively the ratio of the average fishin power per ton for the two methods of propulsion. We have seen that smaller vessels, fo both methods, have higher fishing powers per ton; also motor trawlers are at Lowestoft o the average smaller than steam vessels, particularly for the periods on which thes calculations were based. Hence on this cause alone the average fishing power per ton o motor trawlers would be expected to be higher than that of steam trawlers. A figure in th present calculations which may be compared with the ratio 1·4 of Beverton and Hol would be the ratio of the fishing powers per ton, taken at the means of the two sets o vessels. For steam trawlers the mean tonnage is 143·9, with a fishing power, on the origina scale, of 2·698, and a fishing power per ton of 0·0187. For motor trawlers the figures ar 103·1, 2·549 and 0·0247 respectively. This gives a ratio of 1·32 which is in good agreemen with the 1·4 of Beverton and Holt. Such difference as there is may be accounted for by th difference in the two fleets considered—their motor trawlers were on the average smaller and the steam trawlers larger than in the present calculations.

Though the figure of 1·32 does not represent the real difference between steam an motor trawlers, it is the factor by which the effort in ton-hours by a motor trawler may b converted into ton-hours of a steam trawler. In exactly the same way the rati 2·549 : 2·698 = 0·945 is the factor by which the effort, in simple hours fishing, by Lowestoft motor trawler may be expressed in terms of hours fishing by a steam trawler Both factors, particularly the latter, will depend on the size composition of the two fleets.

Of the other characteristics of a vessel which may be related to fishing power, and whic may be thought to give a closer, or more convenient measure of fishing power, the mos obvious are nett tonnage, length and horse power. All of these are closely connected wit gross tonnage, and for this reason alone would be expected, from the previous analysis, t be closely related to fishing power. In Table IX below the correlation coefficients betwee fishing power and these various factors are shown for the various groups of trawlers. For th Iceland, Skolpen Bank and Milford Haven vessels the correlation coefficient is based o grouped data, and in parentheses is shown the number of groups used.

Table IX: *Correlation coefficients between fishing power and various vessel characteristics*

	Gross Tonnage	Nett Tonnage	Length	Horse Power
Iceland (grouped)	0·903 (17)		0·936 (11)	0·806 (17)
Skolpen Bank (grouped)	0·843 (17)		0·913 (10)	0·802 (10)
Milford Haven (grouped)	0·966 (11)		0·929 (11)	0·935 (12)
Lowestoft Steam	0·844	0·785	0·843	0·585
Lowestoft Motor	0·769		0·765	0·779

he figure for length given is the overall length; for horse power of steam trawlers the ɔminal horse power is used; for motor trawlers the brake horse power is used. The ɔminal horse power is probably rather a poor measure of the real power exerted by the ıgine, and possibly because of this the relation between fishing power and horse power is, r steam trawlers, not so close as those between fishing power and gross tonnage or length. therwise the table suggests that all of the vessel characteristics examined are closely lated to the fishing power, with gross tonnage probably being the closest. Whether either ngth or horse power gives a more convenient measure of fishing power may be decided y examination of Table 7, in which is given, in a manner similar to that of Table 6, the .nge in fishing power and in fishing power per foot or fishing power per horse power. he equations for the regressions on which the table is based are also given. Because the gures are based on grouped data, the range of variation in fishing power for any one set ships is different in Tables 6 and 7. Though the range in fishing power per foot and per ɔrse power is, for some groups of trawlers, e.g. those based at Milford Haven, smaller than ıe range of fishing power per ton, for no group is the fishing power per horse power, or per ɔot virtually constant, as the fishing power per ton is at Iceland, and at Skolpen Bank, for ıe regression based on the standard vessels. Therefore neither length nor horse power can e used in any group as an entirely satisfactory direct proportional measure of fishing ɔwer, and it would seem that gross tonnage is the best measure of those considered.

Possibly the best and most convenient measure of fishing power would be to define an quivalent tonnage', as being proportional to the fishing power. Then for steam trawlers, ver the range 200-750 tons the 'equivalent tonnage' would be the same as the gross ɔnnage, but would be larger than the gross tonnage for small steam trawlers and for ıotor trawlers. Then the measure of fishing effort for all trawlers would be the equivalent ɔns multiplied by hours fishing. For small steam trawlers this equivalent tonnage may be etermined from Figs. 11 and 12. In these a line has been drawn through the origin and the oints above 150 tons; i.e. through points corresponding to the size of vessel for which a roportional relation appears to hold. On this proportional line the true fishing power of a essel of 100 tons, as given by the least squares regression, corresponds to a ship of between 20 and 130 gross tons. The actual values are 126 for Lowestoft and 128 for Milford Haven. Ve may say therefore that the equivalent tonnage of the small steam trawlers of between 0 and 120 gross tons is approximately 1·3 times their gross tonnage.

For motor trawlers, though Table 6 shows that fishing power is not entirely proportional ɔ gross tonnage, there does not appear, from Fig. 13, to be any obvious division, such as ccurred at about 150 tons for steam trawlers. Thus, in default of calculating an empirical quivalent tonnage for each size-group of motor trawler separately, we will take the quivalent tonnage as proportional to gross tonnage. The factor of proportionality will be ıe ratio of the slopes of the proportional lines in Figs. 11 and 12. This is 0·0246 : 0·0174, e. 1·41 : 1, and the equivalent tonnage of a motor trawler is approximately 1·4 times its ross tonnage, at least over the range 60-150 gross tons.

So far we have only considered one factor at a time as influencing fishing power. Of the ıctors considered tonnage and horse power may well act to some extent independently,

and we may examine their effect when considered together. To do this, the partia correlation coefficients, see Kendall (1945), p. 368, have been used. Denoting gross tonnag by the suffix 1, brake horse power by the suffix 2, and fishing power by the suffix y, we hav for the Lowestoft motor trawlers for the ordinary correlation coefficients:—

$$r_{y1} = 0{\cdot}7694 \qquad r_{y2} = 0{\cdot}7792 \quad \text{and} \quad r_{12} = 0{\cdot}8826$$

the first two of these have, of course, already been given in Table IX. Calculating th partial correlation coefficients we have:—

$r_{y1.2} = 0{\cdot}2772$ = correlation coefficient between fishing power and gross tonnage when the effect of horse power is removed.

and $r_{y2.1} = 0{\cdot}3334$ = correlation coefficient between fishing power and brake horse power when the effect of tonnage is removed.

These partial correlation coefficients have also been calculated for the Lowestoft steam trawlers, and for two sets of data on performance given by Hickling (1946a), one fo trawlers on various grounds in 1938, and the other for trawlers fishing off the Old Head o

Table X: *Partial correlation coefficients between fishing power, or performance and gross tonnage and horse power*

	Lt. Motor	Lt. Steam	Hickling (1)	Hickling (2)
r_{y1}	0·769	0·844	0·939	0·908
r_{y2}	0·779	0·585	0·809	0·560
r_{12}	0·883	0·632	0·830	0·607
$r_{y1.2}$	0·277	0·754	0·816	0·863
$r_{y2.1}$	0·333	0·125	0·154	0·027

Kinsdale in July-November, 1942. These correlation coefficients are given in Table X Probably because the nominal horse power is a poor measure of the actual power achieved by the engines, $r_{y2.1}$ is smaller for steam trawlers than for motor trawlers, for which brake horse power has been used. However, for all four sets of data both partial correlation coefficients are positive, though for steam trawlers that between fishing power and horse power is not significant. This would suggest that both tonnage and horse power influence the fishing power, and for the Lowestoft trawlers this may be expressed in the multiple regressions of fishing power as gross tonnage and horse power.

$$y = 0{\cdot}0106\, x_1 + 0{\cdot}00481\, x_2 + 0{\cdot}949 : \text{(steam trawlers)} \quad .. \quad (20)$$

$$y = 0{\cdot}00827\, x_1 + 0{\cdot}00316\, x_2 + 0{\cdot}927 : \text{(motor trawlers)} \quad .. \quad (21)$$

As far as the standardization of fishing power is concerned, this result implies that the previous conclusions in which fishing power, or 'equivalent tonnage', is expressed solely in terms of gross tonnage, are valid only so long as the power of each size of vessel remains constant. For instance, if one size of vessel was fitted with more powerful engines, their fishing power would thereby be increased. This effect may well explain much of the difference between motor and steam vessels; the motor vessels having the more powerful engines. The power of engine fitted to a particular size of vessel is, however, not likely to vary over a very wide range, so that, subject to caution, the gross tonnage may be taken as the single index of fishing power.

THE FISHING POWER OF SEINERS

THE FISHING powers of some fifty seiners have been calculated, on the basis of catch r day relative to steam trawlers fishing at the same place and time. Because seiners rmally fish only during daylight, the amount of fishing done per day varies with the time year, being most during the summer. Thus in comparison with trawlers, which fish ore or less continuously, seiners would be expected to appear most powerful during the mmer. This is borne out in Table XI, in which an analysis of variance has been carried it on the estimated log fishing power, based on catches of plaice, of fourteen seiners, for ch of which three estimates were made, one in the period January-March, and two in the riod May-September. In the analysis the earlier and later of the latter two estimates ve been distinguished.

Table XI: *Analysis of variance of fishing power of* 14 *seiners, distinguishing* 3 *periods of fishing*

	D.F.	Sum of Sq.	Mean Sq.
Ships	13	0·88163	0·06782
Periods	2	0·41369	0·20684
Residual	26	1·61698	0·06219
Total	41	2·91230	

The mean square for periods is significant at the 10 per cent level. The values for the erage log fishing powers for the periods are 1·00 for January-March, and 1·24 and 1·18 r the early and late estimates in the period May-September. As expected, the seiners ppear relatively more powerful in the summer.

The mean square for ships is, however, not significant, so that the present evidence is ot sufficient to distinguish between the fishing powers of different ships. A similar result given in Table XII below, giving the analysis of variance of the estimated log fishing owers of all seiners for which five or more estimates are available. Though the data is not

Table XII: *Analysis of variance of fishing power of* 10 *seiners, irrespective of period of fishing*

	D.F.	Sum of Sq.	Mean Sq.
Within Ships	47	2·77512	0·059045
Between Ships	9	0·83774	0·093082
Total	56	3·61286	

fficient to determine what factor, if any, causes one seiner to catch more fish than nother, it is possible to determine whether tonnage has the same effect for seiners as it oes for trawlers. In Fig. 16 the fishing power, as measured by the equivalent steam trawler ross tonnage has been plotted against the actual gross tonnage, for catches of all demersal pecies (top figure), and for catches of plaice (lower figure). There is obviously no roportional relationship, as exists for trawlers, and in fact the fishing power appears to be ie same for all sizes of ship. The correlation coefficients between fishing power and gross nnage are — 0·05, and — 0·03, based on catches of all species and of plaice respectively. either is significant.

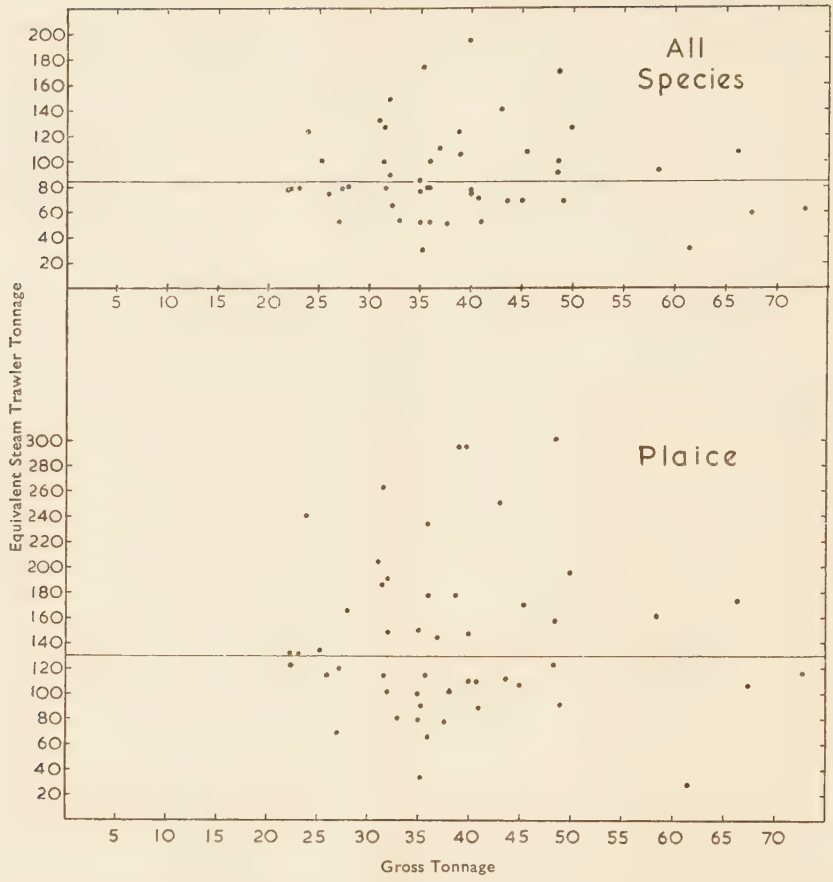


Fig. 16. *Fishing power, in terms of equivalent steam trawler tonnage, of North Sea seiners plotted against gross tonnage; based on catches of all demersal fish (upper figure) and on catches of plaice only (lower figure).*

This result is, of course, not very surprising. For trawls the fishing power is governed by the size of net and speed of tow, in both of which a bigger vessel should have an advantage. In seiners, particularly when fishing from anchor for flat-fish, the catch probably depends on the number of coils of warp used and the manner of shooting and hauling. These factors are probably independent of the size of ship, and are primarily due to the skill of the skipper. For 'fly-dragging' for round-fish, haddock and whiting, when at least at the end of the haul the net is hauled as fast as possible while steaming, it is quite possible that larger ships or more particularly those with more powerful engines, would have a greater fishing power. However, this type of fishing has not been analysed here.

To express fishing effort by seiners in a standard form we will therefore assume that the fishing power is the same for all vessels. The combined estimate of the average fishing power of a seiner is the geometric mean of the individual estimates, i.e. 84 and 130 equivalent steam trawler gross tons, based on catches of all demersal species, and of plaice, respectively, and in terms of catch per day. In terms of catch per hour, using the factor of 1·91 derived from Table III, we obtain the figure 160 and 248 equivalent steam trawler gross tons. It may be noted that the estimates of the equivalent steam trawler tonnage for each individual trip were made on the assumption that the fishing power per ton of North Sea steam trawlers was constant, and this assumption has been shown to be not quite true. However, the trawlers with which comparisons were made were all between 180 and 240 gross tons, and in this range the fishing power is proportional to the gross tonnage, and in the sense defined earlier the equivalent tonnage of these trawlers is the same as the gross tonnage, and hence the equivalent tonnage of 160 or 248, determined here for seiners, has the same meaning and is in the same units as the equivalent tonnages defined earlier for

ıall steam trawlers, and for motor trawlers. For some purposes of possible regulation e relative catch per year is important. Though this is not a real constant, but depends on e possibly variable custom of the fisherman, a fair estimate of the relative catch per year trawlers and seiners may be obtained on the basis of their spending respectively 300 and)0 days at sea per year. On this basis a years fishing by a seiner was equivalent to about) and 90 equivalent steam trawler gross tons, for all demersal species and plaice alone.

THE FISHING POWER OF PAREJAS

HE NUMBER of pareja, or pair vessels fishing from English ports is very small, being ınfined to a few ships working from Milford Haven. The fishing powers of eight pairs ıve been calculated at the same time as the trawlers working from Milford Haven, these timates being based on forty estimates from single trips. In the analysis of variance below these individual estimates, the within-ship mean square is greater than the between-ship

Table XIII: *Analysis of variance of fishing powers of Pareja vessels*

	D.F.	Sum of Sq.	Mean Sq.
Between Ships	7	0·06911	0·0099
Within Ships	32	0·81147	0·0254
Total	39	0·88058	

ean square, the variance ratio of 2·57 actually being just significant at the 5 per cent level. here is therefore certainly no evidence here to distinguish between the fishing powers of fferent pairs. The sizes and other characteristics of the ships, which are all between)0 and 220 gross tons, are very similar, and therefore the only differences between ships 'e likely to be differences in the skill of skippers. The combined estimate, that is the :ometric mean of the individual estimates, gives a mean fishing power of a pair as 6·483, :. 3·24 per vessel. From Fig. 11, and reading off from the proportional line through the ›ints above 150 gross tons, we find that a fishing power of 3·24 corresponds to a gross ınnage of 318 tons. Thus, when it is one of a pair, a vessel of some 200 tons has an ıuivalent tonnage of about 320 tons, and the equivalent tonnage of the pair taken together 640 tons. This figure of 320 tons agrees well with Hickling's (1946a) figure of 350 tons, ısed on performance, i.e. catch per 100 hours irrespective of area. The agreement is even oser if we read off in Fig. 11 from the regression fitted to all the points rather than to the :oportional line. On the regression line a fishing power of 3·24 corresponds to a gross ınnage of 353.

The figure of 320 tons based on catch per hour may be converted into catch per year, least for present conditions. The number of days at sea per year is probably about the ıme for pair-boats and for trawlers, but in the region to the West of Ireland in 1953, eam trawlers had 13·5 hours fishing per day at sea, and pair-boats 7·4. Therefore, per :ar, a pair-boat was equivalent to $320 \times 7{\cdot}4/13{\cdot}5 = 175$ steam trawler gross tons.

THE RELATION OF FISHING POWER AND PERFORMANCE

MAJOR part of the computational work involved in calculating fishing power arises ırough the need to compare only ships fishing at the same time and place. Much labour

would therefore be saved if performance could be used as an approximation to fishin power, i.e. if simply the catches per hours fishing were compared without reference to th position and time of capture. Performance will be an accurate measure of fishing powe provided that the density of fish is the same at all times and places, or at least that th density of fish at one place is not correlated with the fishing power, or other characteristic of the vessels fishing there. Unfortunately, there is a marked segregation of fishing position according to size, not only between the regions fished, e.g. the biggest vessels going to th Arctic, etc., but also within regions, e.g. for Lowestoft vessels fishing in the North Sea.

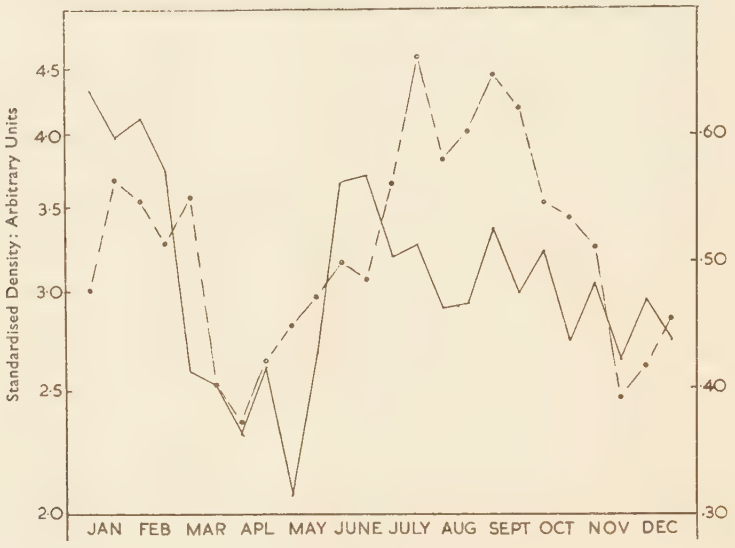


Fig. 17. *Standard density, i.e. catch per standard fishing effort, in areas of the North Sea fished mainly by the smaller Lowestoft trawlers (full line), and larger trawlers (broken line). To show the divergence in July-October, but approximate equality for the rest of the year. Logarithmic scale shown on left.*

Considering first the variation within one region, in Fig. 17 the mean density during eac fortnight of 1951 for two sections of the North Sea have been plotted. The two area comprise the rectangles H6, 7, 10 and J7, fished predominantly by the larger trawlers shown as a broken line, and rectangles F1, 5 and G2, 3, 4, and 5 fished mainly by th drifter trawlers and the smaller motor trawlers, shown by a full line. In comparing the tw graphs, it should be realised that the composition of the catches and hence the value pe cwt. is not the same for both areas, and also varies from month to month. As fishermen ar interested in the value of their catch, 50 cwt. (say of large plaice) from the large ship are may be more attractive than 75 cwt. (say of small plaice and skate) from the small shi area. This explains why in say January when the density in the small ship area is greate than in the large ship area, the latter is still fished, even though it lies further from por and thus involves greater steaming time. Taking the year as a whole, the full line on th average is above, but only slightly above, the broken line, but in the period July t September the difference is considerable. This implies that taken over the whole year th performance, i.e. simple catch per unit effort, should be a good measure of fishing powe though probably overestimating the fishing power of the larger vessels. The performanc during July-September, however, would considerably overestimate the fishing power of th larger vessels. These results are shown in Figs. 18(a) and (b), in which the performances, fo July-September and for the whole year respectively, have been plotted against fishin power. For the whole year [Fig. 18(b)], the points lie almost exactly on a proportional lin but the departure from proportionality is considerable in Fig. 18(a). Using logarithms, w may, as in (11), fit a regression line of the type

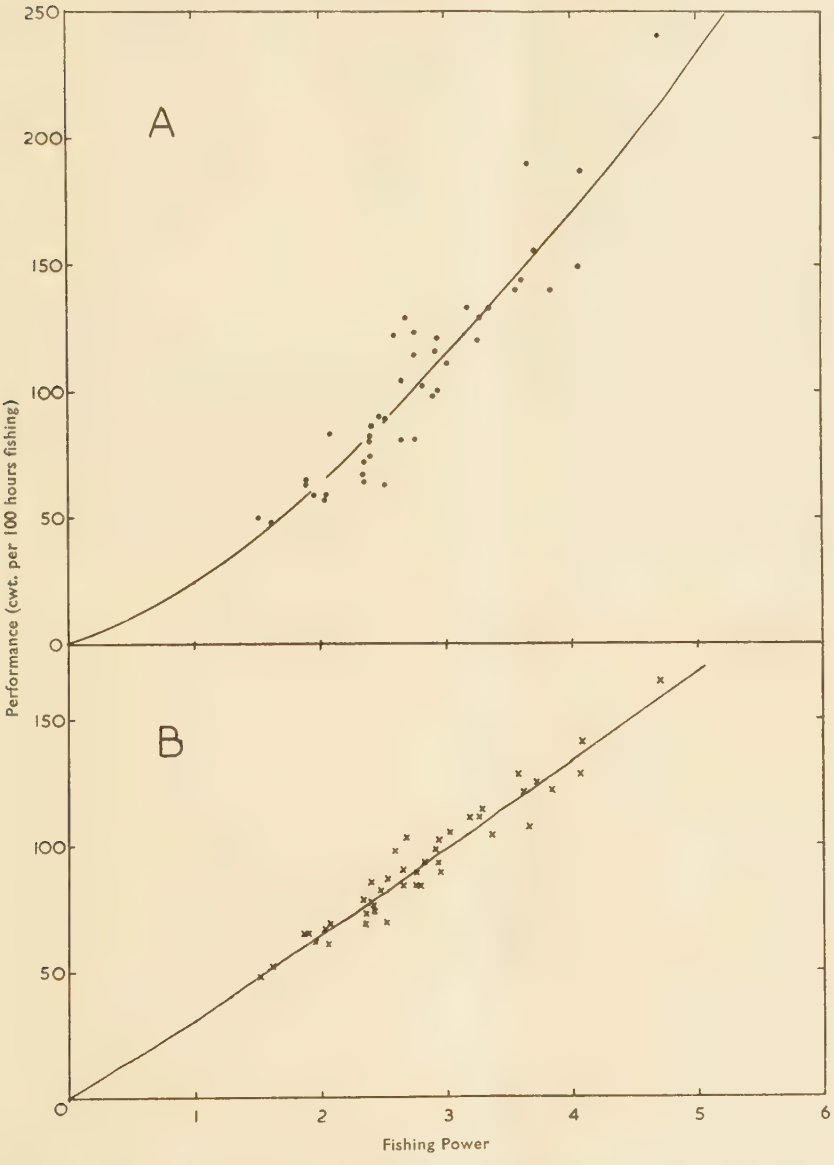


Fig. 18. *Performance (catch in cwt. per* 100 *hours fishing) plotted against fishing power for Lowestoft trawlers* (a) *in July-October*, 1951 (*upper figure*) *and* (b) *for the whole year* (*lower figure*). *Showing the fitted log-log regression, virtually proportional in the lower figure, but markedly curvilinear in the upper figure.*

$$\log Y = \log a + b \log X$$

or $$Y = aX^b$$

where X = Fishing power

Y = Performance

f performance is a proper measure of fishing power, i.e. is proportional to it, then $b = 1$.

Fitting the regressions,

we have for the whole year $b = 1{\cdot}043$,

and standard deviation of $b = 0{\cdot}042$

and for July-September $b = 1{\cdot}412$

and standard deviation of $b = 0{\cdot}086$

The departure from proportionality ($b = 1$) is highly significant in the second case. Th fact that b is greater than one indicates that the more powerful vessels have relativel greater performance. Similar calculations for vessels fishing at Iceland, shown in Fig. 19 give $b = 1{\cdot}202$ with a standard deviation of $0{\cdot}151$; the departure from proportionality i not significant. The results suggest that for ships fishing in one region (North Sea, o Iceland), performance may be a not unsatisfactory measure of fishing power, at least to first approximation.

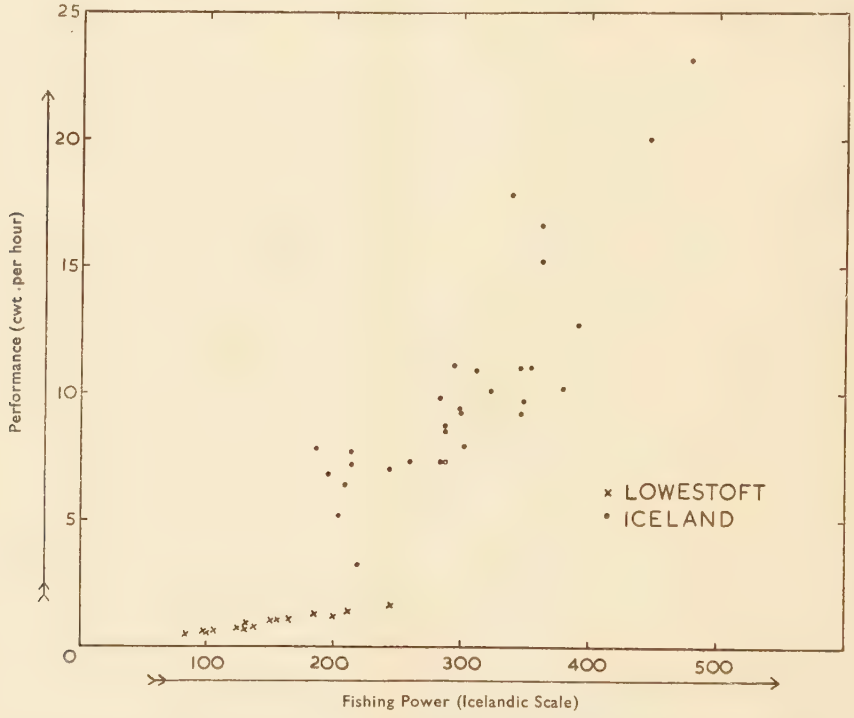


Fig. 19. *Performance (catch in cwt. per 100 hours fishing) plotted against fishing power for trawlers fishing at Iceland, and in the North Sea. Showing the approximately proportional relation within each group, but the marked difference between the two groups.*

A very different result is given when catches from different regions are not differentiated In Fig. 19 the previous data for the North Sea and Iceland have been combined in one figure using the conversion factor for the fishing power of the North Sea vessels found earlier The difference between the two sets of points is very marked. Obviously, if performance (catch per hour) were used as a measure of fishing power, the power of the North Sea vessels would be very seriously underestimated. In contrast to the variations in density within the North Sea, or the Iceland region, which are relatively small, there is a very big difference between the density of fish at Iceland and in the North Sea. As judged by the difference in slope of the two lines in Fig. 19, the density at Iceland is about five times that of the North Sea. The actual catch per 100 hours by English steam trawlers in 1951 in the

vo regions were 1,170 cwt. and 138 cwt. respectively, a ratio of about 8 : 1, the departure om the figure of 5 : 1 being due to the bigger size and greater fishing power of vessels at eland. Despite the difference in density the North Sea is still a paying ground for the naller ships because of the small steaming time and the better value, weight for weight, the North Sea fish.

Performance can therefore only be used as an approximation to the true fishing power r comparisons within a fairly restricted range of place and time, but with these strictions it may serve as a fair approximation.

COMPARISON WITH OTHER RESULTS

BEVERTON AND HOLT (in press) have calculated, for the English North Sea fleet in 947, the fishing power in exactly the same sense as used here, though by a slightly different ethod. In Fig. 20 the mean fishing power of each size group of trawlers as calculated by iem has been plotted, together with the regression line for Lowestoft steam trawlers as

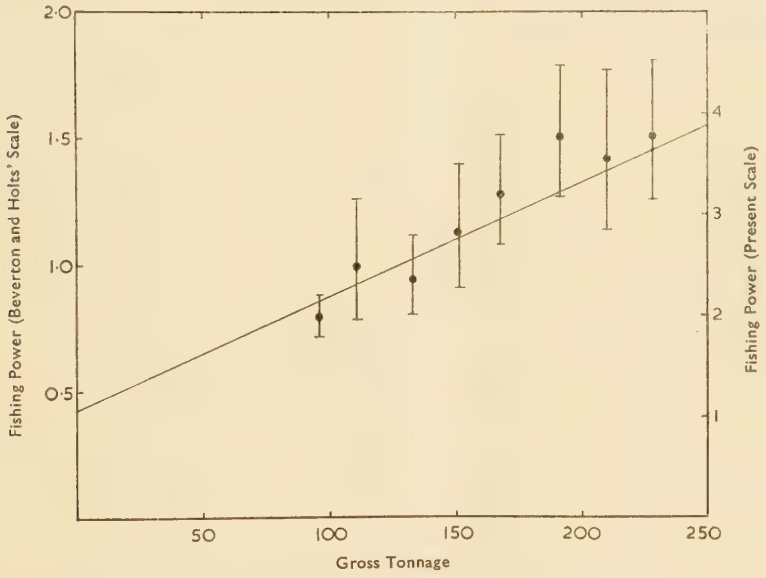


Fig. 20. *The regression of fishing power on gross tonnage of Fig.* 12 *plotted in the same figure as the data of Beverton and Holt, showing the means of their tonnage groups, together with limits plus or minus twice the standard deviation. Illustrating the agreement between the two sets of data.*

calculated from the present data. Lines extending plus or minus twice the standard leviation have also been drawn for each of Beverton and Holt's points, and these show that here is satisfactory agreement between the points and the regression line, i.e. between heir estimates of fishing power and the present ones.

Hickling (1946a) only calculated performance, so that his results are not strictly comparable with the present ones. There is some variation between his sets of data; in all, performance increases with tonnage, but in one case this increase is less than proportional o the increase in tonnage, and in two others the performance of the larger ships is proportionately greater than that of the smaller ships. He also found, on the basis of catch per day's absence, that Belgian motor trawlers were, ton for ton, more powerful than the British steam trawlers. His results are therefore in general agreement with the present ones. For herring trawlers Hickling (1946b) found, for three sizes of trawlers, average 180, 220

and 270 gross tons, had catches per 100 hours fishing of 210, 254 and 307 cwt. respectively This gives a catch per 100 ton-hours of 1·167, 1·155 and 1·137; that is, the performanc almost exactly proportional to gross tonnage. In this case he was considering the catche on only one ground during a short season, and the figures may be taken as equivalent to th fishing power. Boerema (1950) calculated a 'fishing capacity factor' for a number of Dutc steam trawlers, on the basis of relative catch per day's absence during the same month though not necessarily on the same ground. This factor therefore corresponds to somethin between our 'fishing power' and 'performance'. Plotting it against indicated horse powe Boerema found a relation not very different from a straight line, though not proportiona the ships with the greater horse power having relatively greater fishing capacity.

Apart from these papers relatively little has been published on the relation betwee fishing power, or performance, and vessel characteristics, based on results of a whole flee However, there have been several direct comparisons of ships fishing side by side e.g. Margetts (1949a, b, 1955), Parrish (1951), Graham M. (1954). These experiments hav generally been designed to show either differences in the composition of the catches, by siz or species, or the effects on the catch of changes in the rig of the gear, the latter being ofte remarkably large. In most of the comparisons at least one of the ships has been a researc vessel, for which there is not the urgent financial incentive to use the best gear, and th best rig, for the ground being fished as there is for a ship fishing commercially. For instance fishing against the English research vessel PLATESSA, the Danish research vessel DANA used special small experimental trawl, and was definitely outfished (Margetts, 1955). Again, whe PLATESSA was fished against her sister ship, KIRKLEY, a commercial trawler, with the ship using almost identical trawls, the KIRKLEY definitely appeared the more powerful, thoug the presence or absence of a tickler chain made a considerable difference (Margetts, 1955 As the number of hauls used are also usually rather limited, giving rise to considerabl sampling error, these experiments do not help greatly in supporting or denying the preser results for trawlers, except in so far as the larger vessels, using the bigger trawls, had th better catches. Comparing the commercial seiner ARABIS with the two research trawler SIR LANCELOT, a steam trawler of 300 tons and PLATESSA, a motor trawler of 112 tons Margetts (1949b) found that their catches of plaice, in pounds per hours fishing were 67 25 and 13 respectively, giving a ratio of catch per unit effort of seiner : trawler o 2·7:1 and 5:1 for SIR LANCELOT and PLATESSA respectively. These are considerably mor favourable to the seiner than the ratios of their equivalent tonnages (in the sense define earlier), which are 248:300 and 248:157, i.e. 0·8:1 and 1·6:1 respectively. Several factor may have caused this inconsistency. First, the experiment was carried out on a groun chosen by the seiner, with the trawlers fishing as close as possible, in contrast to the norm situation, where each vessel fishes in the position best suited to it. To this extent, of course the comparisons in this paper, which are between ships fishing up to 30 miles apart ar poorer measures of comparative fishing power than the direct experimental method. Also while, as has been suggested, the two research trawlers may have fishing powers rathe below the average for their size, ARABIS had a fishing power, as estimated in the analysi of seiner power, rather above the average. Finally the trip-to-trip variation in the catche of seiners is considerable; in Table XI the residual variance was 0·062, corresponding to coefficient of variation of about 80 per cent. The two comparisons between the fishin powers of trawlers and seiners are probably not really contradictory.

An important comparison between two commercial trawlers was made by Davis (1934) in which two sister ships using trawls differing only in the size of the cod-end mesh fishe side by side. His data suggested that, above the selection size, the ship with the large mesh had noticeably greater catches. This effect, possibly due to better flow through th net, has been noticed by other workers, in particular for the trawlers fishing for haddoc on the Georges Bank since the new mesh regulation (Graham, H. W., 1954). This effec probably makes an exception to the assumption made earlier (page 3), that a commercia ship will use the most efficient gear for the ground being fished. While the losses of small but possibly marketable, fish through the large meshes are obvious, the gains in using large mesh, of a few per cent on the average over many hauls, is not so obvious. Thus it i likely that trawlers will use a mesh size smaller than that giving the best catches. This i quite apart from any question of the conservation of the smaller fish. In a heavily fishe

ck a mesh size larger than the most efficient one may be necessary to protect the small h, and so give, in the long run, better catches.

Because of this effect, fishing power of trawlers and hence their fishing effort, should erefore be given in terms of the mesh size in use.

THE MEASUREMENT OF FISHING TIME

N THE English statistics three measures of the duration of the fishing activities of awlers are given; number of trips, days absence, and hours fishing. These details are otained from the 'D' forms mentioned earlier. The first two measures are likely to be own very accurately, the number of trips being merely the number of forms, and the ngth of trip given on each form being obtained from the readily known dates of departure d arrival. The time spent fishing is obtained as the product of the number of hauls times e average length of haul, these details being obtained by interviewing the mate of the awler at the time of landing. This may be up to a fortnight after the earlier hauls, and thus ere is considerable possibility of error. That is, while the true number of trips and days sence are accurately recorded, the recorded number of hours fishing may depart quite idely from the true figure, but this does not imply anything about which is the most curate measure of the true fishing activity.

On theoretical grounds, the number of hours fishing does provide the best index of the tent of fishing, for it does not contain such unwanted factors as the time spent steaming and from the grounds, time spent 'dodging' in bad weather and others, which appear in e returns of days absent, and to some extent also in figures for days fishing, which have een used in German statistics. The greatest disadvantage in days absence is that the lation between it and the true fishing time is liable to be correlated with other factors. ne such correlation is demonstrated in Table 8. This gives, for the trips of trawlers fishing the Barents Sea in the last quarter of 1951, which were used for the fishing power lculations of the previous sections, the average length of trip, the average number of ours fishing per trip, and the ratio hours fishing: days absence. The trawlers have been ivided into five tonnage classes, and the figures calculated for each tonnage class each onth. The results show that with increasing tonnage, the length of trip tends to decrease,

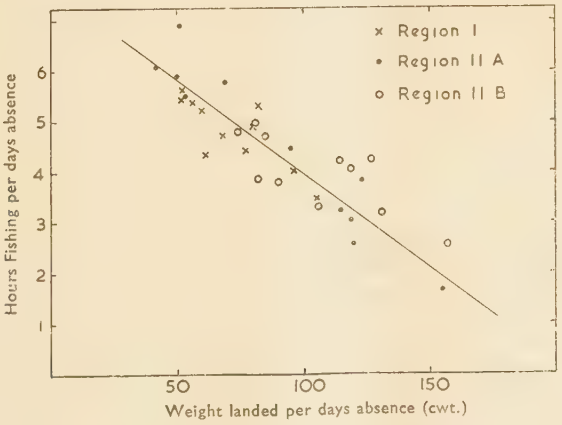


Fig. 21. *The ratio of hours fishing to days absence plotted against the weight landed per days absence for the regions I (Barents Sea), IIa (Norway coast) and IIb (Bear Island—Spitsbergen) for the years* 1930-38 *and* 1946-7. *Showing the falling off in hours fishing per day at times of good fishing.*

but the amount of fishing, as measured by the reported hours fishing, increases, and hen of course, the ratio hours fishing : days absence also increases. This effect is readi explained by the larger trawlers also being the newer and faster ships. They therefore spen less time steaming to and from the grounds, and can therefore spend proportionately mo time actually fishing.

An even more serious effect is the correlation between hours fishing per day and th abundance of fish, as has been pointed out by Beverton and Parrish. This is demonstrate in Fig. 21, in which the hours fishing per day has been plotted against the catch per day all demersal species by English trawlers in the three Arctic regions (Barent's Sea, Be Island and Spitsbergen, and Norway Coast) for the years 1930-38, and 1946-47. The years were chosen to give a relatively homogeneous fleet; after 1947 large post-war trawle made up an increasing part of the fleet. At high levels of abundance the hours per da drop off, this being apparent in all three regions. For the purposes of this diagram, catc per day's absence is used as the measure of fish abundance. Normally, as will be show catch per hours fishing is much the better, but while the former is measured independent of the hours fishing, it is possible that a relation similar to that observed in Fig. 21 betwee hours per day and cwt. per day may arise between the reported hours per day and cwt. pe hour through inaccuracies of measurement. That is, if the number of hours is ver inaccurately reported, in those years when it is over-estimated, the hours per day will b increased, and the cwt. per hour decreased, giving the inverse relationship. The observe relation in Fig. 21, however, cannot be due to such artificial causes, but reflects some re form of 'vessel saturation.'

This form of 'saturation' with hours per day falling off at high fish densities may b occurring in several ways. Firstly, the time needed to get a full catch will be less, so th proportionally more time will be spent steaming; this will also appear as a reduction in th duration of trip. In fact, in 1946-47, when the abundance of fish was greatest, the leng of trip was actually greater than before the war, because of the changed economic condition After the war the price of fish was controlled, and quantity was much more important tha quality. Before the war, quality was more important, and ships made shorter trips, returni far from full up, to ensure landing their fish fresh, and fetching a reasonable price. Secondl at extremely high fish densities, fish are caught faster than they can be gutted and p below, so that fishing is stopped while the decks are cleared of fish. This is known to ha been happening at Hope Island even in 1948 (Graham et. al., 1954), while an exception record is of a trawler making only four hauls a day, each of about half an hour, with th

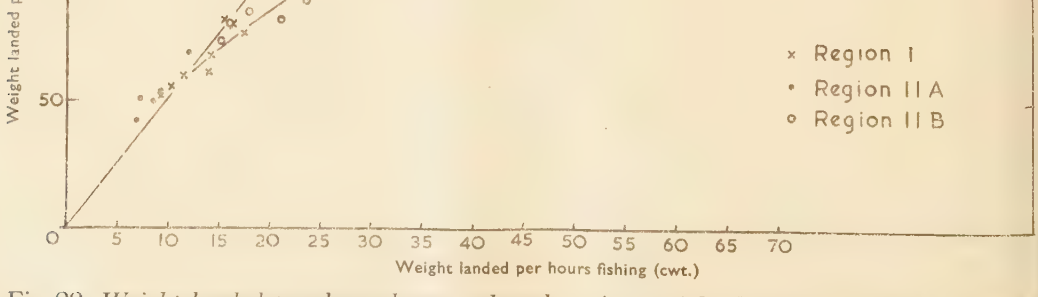


Fig. 22. *Weight landed per days absence, plotted against weight landed per hours fishing, fo regions I, IIa and IIb,* 1930-38 and 1946-7, *showing the apparent 'saturation' in catch pe day at a level of* 150-200 *cwt. per day.*

: of the time spent gutting (G. C. Trout, personal communication). At less extreme ısities, while fishing is not actually stopped, the proportion of time the trawl is actually the bottom may be seriously reduced. Extra time will be spent 'bagging' the fish aboard, l the length of haul may be reduced, thus increasing the proportion of time spent shooting l hauling. The catch per days absence will therefore progressively underestimate the e abundance of fish. This is shown in Fig. 22, in which the weight landed per days ence of all species is plotted against the weight per hours fishing, for the same years l regions as Fig. 21. The falling off is obvious, the catch per day apparently reaching a ıration level in the region of 170-200 cwt. per day. A saturation figure at about this level easonable, for on the average a trawler's crew can gut and put fish below at the rate of ne 500 cwt. per day. At this rate a good catch of some 3,000 cwt. can be taken on board in days, which with ten days steaming, gives a maximum catch per days absence of some) cwt.

The scatter about the line in Fig. 22 is quite small. Such as it is, it includes the effects of ınges in trip length due to factors other than fish abundance, e.g. differences in loss ime due to bad weather, as well as inaccuracies in the reported number of hours fishing. : may therefore deduce that over the activities of a large number of ships the reported mber of hours fishing is accurate. The number of days absence, however, gives a picture the effort, and catch per unit effort, that is almost entirely unreliable at fish densities ove 100 cwt. per days absence (25 cwt. per hours fishing), and is not entirely reliable en at densities of 50 cwt. per day (10 cwt. per hour).

EFFORT AND CATCH PER UNIT EFFORT AT ICELAND

HE RESULTS of using the more refined measures of fishing effort considered in this per may be well demonstrated by the English fishery at Iceland. Of the generally used asures of effort, statistics of the number of days absence are available from 1906 wards, and of hours fishing from 1924 onwards. Days absence have therefore been nerally used to give the longest series. The ratio of hours fishing to days absence has anged considerably since 1924, increasing from 5·2 in 1925 to 6·6 in 1937, and after lecrease just after the 1939-1945 war, has further increased to 6·8 in 1952. The changes the average tonnage, and hence fishing power, of the trawlers fishing at Iceland may be ıged from Fig. 16. Statistics for ton-hours, that is the product of the gross tonnage and urs fishing, summed over all trips is not available. However, an approximation to it is en by the product of the average tonnage and the total hours fishing, which have been culated for the years 1946, 1948, 1951 and 1954. If there is no correlation between hours ning and size of vessel, this figure is an unbiased estimate of the ton-hours; actually ble 8 suggests that there is a positive correlation, the larger vessels doing slightly more ning. The true ton-hours will therefore be greater than the product of mean tonnage times al hours, but the difference will be small, and about the same for each year, so that the ter figure may be taken as the best available index of effort. In Table XIV the resulting ures of effort, and catch per unit effort of cod are given for the three years 1946, 1948 d 1951, expressed as a percentage of 1946 and are contrasted with those obtained by ng other measures of fishing effort. The figures used as the total catch of cod have been justed to be in terms of weight gutted, heads on; in 1946 and 1948 considerable quantities cod were headed at sea. For these headed fish the landed weights have been increased by per cent.

Additional, and to a great extent independent, evidence that the change in abundance cod between 1946 and 1951, as measured by the catch per ton-hour of the whole fleet realistic, may be obtained by considering the catch and effort of individual ships. In ıble 9 the catch, effort, and catch per unit effort of cod by eight ships which fished at the ne statistical rectangle during corresponding months of 1946 and 1951 are given.

Table XIV: *Catch per unit effort of Iceland cod in* 1948 *and* 1951, *as a percentage of* 1946, *for various measures of effort*

Unit of Effort	1946	1948	1951
Days Absence	100	94	95
Hours Fishing	100	74	65
Days × Mean Tonnage	100	89	74
Hours × Mean Tonnage	100	69	51

In these comparisons no correction has been made for heading, which took place on all b two of the 1946 landings. Thus the 1946 catches, and catch per effort are underestimat of the true figures. The table also gives the ratio between the 1946 and 1951 catch per da and catch per hour of cod. These are, as might be expected, very variable but only for or ship is the catch per hour up, and in two the catch per day is up. Inspection of the catch shows that this increase is, for one ship, almost certainly because in 1946 her catch w mainly haddock, and in 1951 mainly cod; that is, in 1946 she was fishing mainly for haddo and the catch per unit effort for cod would be expected to be low. Probably the be combined estimate of the 1951-1946 ratio is obtained as the geometric mean, i.e. the anti-l of the mean of the logarithms of the ratios, as the arithmetic mean of a set of ratios is liab to serious bias. This gives, as the collective estimate of the catch per unit in 1951 as percentage of 1946, 29 per cent based on hours fishing, and 54 per cent based on da absence.

These results, showing the big alterations which may be made in the estimates density by the use of different units of fishing power and effort, suggest that it is wor while to make some attempt at estimating the effort in terms of ton-hours for the earl years when the average tonnage was not known directly. To do this it was assumed that t average size of trawlers fishing at Iceland in 1920 and earlier years was 250 gross ton This figure is not unreasonable, though probably errs in being too large.

Using Fig. 14 as a guide to the general date and size of new construction, a graph average tonnage against year was drawn roughly to pass through 250 tons at 1920, a increasing, particularly between 1934-1938, to 345 tons in 1946 and 440 in 1951. The hou fishing before 1924 were calculated on the assumption that the ratio hours fishing : da

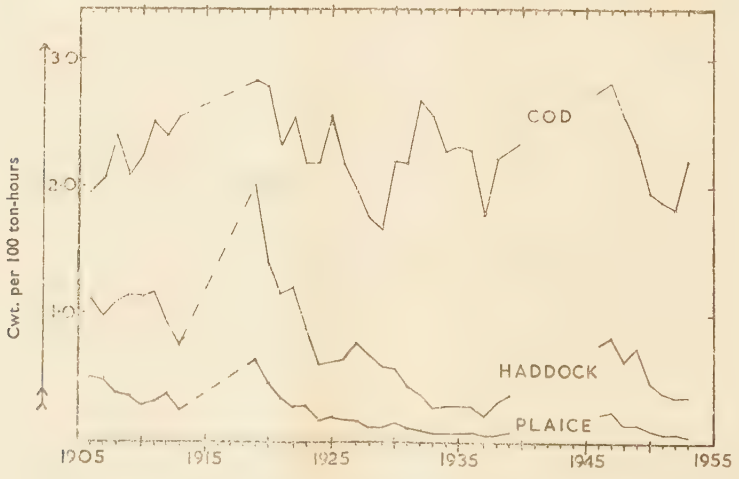


Fig. 23. *Catch per standard effort* (*cwt. per* 100 *ton-hours*) *of cod, haddock and plaice by English steam trawlers at Iceland,* 1906-1953.

sence, was the same then as the average for the years 1924 to 1927. These assumptions abled a value for the effort in ton-hour units to be assessed from 1906 onwards, except interruptions for the two wars. The resulting catch per effort figures for cod, haddock d plaice are shown graphically in Fig. 23.

Though any proper analysis of the state of the stocks is beyond the scope of this paper, ne conclusions are possible from the general trend of the curves. Those for haddock and uice are very similar, and show very clearly the effect of the respite from fishing during e two wars, during which the density increased very markedly, only to decrease once ore when heavy fishing re-started. It seems almost certain that a proper analysis would ow that reduced fishing on these species would result not only in increased catch per it effort but also in a greater sustained yield.

For cod, the catch per ton-hour shows fluctuations about a remarkably steady mean el. This may be contrasted with the increasing trend which is a feature of the catch per ys absence, and which appears to be due simply to the increasing size of trawlers. owever, there is still no evidence of a marked decline, despite the increased amount of hing, particularly up to 1930, and though there is a peak after each war, neither is preciably higher than the peak in 1932-3, which occurred during a time of very high ort. The effect of fishing on the stock therefore is probably not too severe, and an creased yield of cod would be achieved by a moderate increase in the fishing effort on it.

The English fishery at Iceland is an example of one where the use of a poor measure fishing power gave anomalous and misleading results. Apparently, without correcting r changes in the size of vessel, there had been a continuous increasing trend in the undance of cod since 1900 which has been shown to be probably entirely due to the anges in the size of trawlers. An example of a fishery on which a poor choice of the easure of the extent of fishing is given by the English fishery on the Norwegian Coast

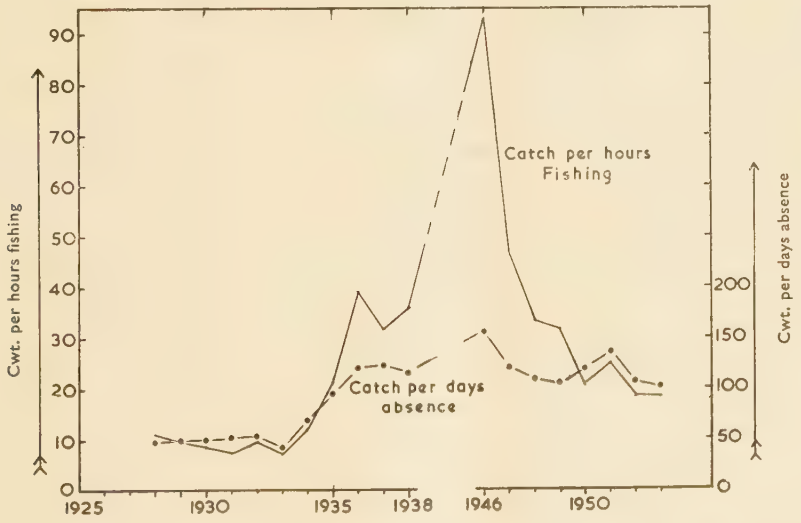


Fig. 24. *Catch per days absence (broken line) and catch per hours fishing (full line) of all species in Region IIa (Norway Coast) by English steam trawlers, 1928-1953. Showing damped fluctuations in the catch per day.*

Region IIa). In Fig. 24 the catch per days absence and catch per hours fishing of all emersal fish (of which cod is the principle species), have been plotted. The dotted line atch per day), after a marked increase from 1931-35, has since fluctuated only to a minor xtent. The catch per hour, (full line) has varied enormously particularly just after the war. hese fluctuations, due either to varying strengths of year classes or to the partial rotection during the war have been almost entirely damped away, as measured in catch er day, due to 'vessel saturation'.

SUMMARY

THE CONCEPTS of fishing effort and fishing power are defined. Methods of calculatir fishing power are derived, and the fishing power of some 500 English trawlers, and al some seiners and pair vessels are obtained.

For steam trawlers above about 150 gross tons, the fishing power is approximate proportional to gross tonnage. Steam trawlers of less than 150 gross tonnage, which grou is comprised almost entirely of drifter-trawlers of 95-110 gross tons are, ton for ton, abo 1·3 times as powerful as the larger trawlers. For motor trawlers fishing power is also close related to gross tonnage, and the smaller ships are also ton for ton somewhat more powerf than the larger ones. Motor trawlers are, ton for ton, 1·4 times as powerful as the larg steam trawlers.

The variations in fishing power of a ship about the average for its size may be large ascribed to the fluctuations in the success of different trips by the same vessel.

Fishing power of trawlers is also closely correlated with the length of a ship, its n tonnage and horse power. These factors are all closely correlated. Calculating the parti correlation coefficients between fishing power and tonnage and horse power, and th estimating the effect of each factor alone, the other being held constant, showed that bo gross tonnage and horse power influenced the fishing power. For motor trawlers the bra horse power had the slightly greater effect, but for steam trawlers the nominal horse pow had a smaller effect than gross tonnage.

The concept of equivalent tonnage was defined, being proportional to the fishing pow of a ship. For large and medium steam trawlers the equivalent tonnage is equal to t gross tonnage, but is 1·3 times the gross tonnage for steam drifter-trawlers, and 1·4 tim the gross tonnage for motor trawlers.

The fishing power of seiners is found to be independent of the size of ship, over t range 20-80 gross tons, and the equivalent tonnage of a seiner, in terms of catch per ho is 250 tons. The equivalent tonnage of a pair boat is 320 tons, in terms of catch per hou The fishing capacity per year of both these kinds of vessel is reduced because of the fewer hours worked.

Performance, i.e. catch per hour irrespective of position or time of capture is shown t be in some circumstances a useful first approximation to fishing power.

The number of days absent from port, and the number of hours fishing, are discusse as measures of the duration of fishing, and the former is shown to be unreliable in heav fishing.

The effect of using different measures of fishing effort are illustrated from the statistic of the English fisheries at Iceland and on the Norwegian coast.

APPENDIX (Tables 1-9)

ble 1: *Fishing activities of certain trawlers in the Bristol Channel in* 1951, *showing the duration of the trip and the logarithm of the catch per ten hours fishing*

Ship's Code Number	February							March																							
	22	23	24	25	26	27	28	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
391																																						
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226																																						

Table 2: *Catch per unit effort of fourteen standard ships fishing at Skolpen Bank. (Logarithms of the weight caught per hours fishing: in cwt.)*

Ship	Trip 1	Trip 2	Trip 3	Mean
1	0·95	0·91	1·02	0·960
2	1·14	1·04	1·04	1·073
3	1·05	0·91	0·96	0·973
4	1·10	0·96	1·13	1·063
5	1·17	1·17	1·23	1·190
6	1·16	1·11	1·38	1·217
7	1·07	0·58	0·98	0·877
8	0·98	0·97	1·02	0·990
9	1·12	1·06	1·19	1·123
10	1·22	1·08	1·27	1·190
11	1·02	0·85	1·01	0·960
12	1·04	0·82	1·13	0·997
13	1·05	1·29	1·19	1·177
14	1·09	1·03	1·06	1·060
Mean	1·083	0·984	1·115	1·061

Table 3: *Comparisons between pairs of standard ships fishing from Lowestoft, to give the relative fishing powers. Part of complete table only. For explanation see text.*

Ship	1	2	3	....	30	Σx	1/30 Σx
1	X	0·465	0·580	....	0·510	14·249	0·475
2	0·535	X	0·469	....	0·462	12·064	0·402
3	0·420	0·531	X	....	0·461	12·825	0·428
.	.	.	.	....	.	.	.
.	.	.	.	....	.	.	.
.	.	.	.	....	.	.	.
30	0·490	0·538	0·539		X	13·218	0·441

non-standard ships from their catches and those of standard ships (Nos. 392, 395, 306 and 401).
For full explanation see text.

Ship's Code Number	Log Fishing Power of standard ships	Log catch per ten hours, and log density (in parenthesis)																														Estimated Log Fishing Power from each trip.		
		February								March																										
		22	23	24	25	26	27	28		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
391				1·35														1·27																	1·22		0·39	0·52	0·49
392	0·38						1·37 (0·99)																								0·96 (0·58)									
395	0·37						1·32 (0·95)														1·14 (0·77)												1·10 (0·73)							
353								1·52																1·28														0·56	0·53	
397							1·45														1·25													1·32					0·49	0·50	0·66
396							1·23																											1·15					0·27	0·49	
399							1·23												1·17														0·94						0·27	0·42	0·28
306	0·47																							1·23 (0·76)																
401	0·47						1·40 (0·93)													1·20 (0·73)																				
226																1·35																						0·52		

Table 5: *Log fishing powers of certain Milford Haven trawlers as estimated: (a) on the 'castle' scale, and (b) on the drifter-trawler scale*

Ship	On Castle Scale		On D/T Scale		B – A
	Trips	Mean log F.P. (A)	Trips	Mean log F.P. (B)	
1	4	0·31	1	0·56	0·25
2	1	0·40	5	0·62	0·22
3	1	0·19	13	0·41	0·22
4	3	0·45	1	0·78	0·33
5	3	0·49	4	0·71	0·22
6	2	0·34	2	0·38	0·04
7	2	0·23	2	0·57	0·34
8	5	0·31	1	0·40	0·09
9	1	0·38	3	0·48	0·10
10	1	0·26	14	0·45	0·19
11	2	0·50	1	0·94	0·44
12	2	0·23	3	0·70	0·47
13	1	0·35	1	0·52	0·17
14	2	0·38	1	0·53	0·15
				Mean	0·23

Table 6: *Range of fishing power and fishing power per gross ton within various sets of trawle*

Group	Limits of Gross Tonnage	Fishing Power	F.P. per ton	Range of Variation %	
				F.P.	F.P./ton
Iceland	800 250	590 197	0·738 0·787	199·9	6·7
Milford Haven	350 94	3·23 1·55	0·0092 0·0165	107·9	79·1
Lowestoft (Steam)	200 95	3·33 2·15	0·0167 0·0226	55·2	35·6
Lowestoft (Motor)	160 60	3·53 1·81	0·0221 0·0301	95·3	36·2
Skolpen Bank (all ships)	800 300	19·1 10·1	0·0238 0·0336	89·5	40·7
Skolpen Bank (standard ships)	800 300	19·8 7·3	0·0247 0·0244	170·0	1·3
North Sea (Beverton & Holt)	265 96	1·47 0·80	0·00554 0·00829	84·4	49·6

ble 7: *Range of fishing power, fishing power per foot, and fishing power per horse power within various sets of trawlers*

Ships and Regressions	Limits of Length (ft.)	Fishing Power	Fishing Power per foot	Range of variation %	
				Fishing Power	Fishing Power/foot
lpen Bank (all ships) $= 0{\cdot}137x - 8{\cdot}81$	140 190	10·34 17·18	0·0739 0·0904	66·1	22·3
and $= 0{\cdot}053x - 4{\cdot}96$	140 190	2·42 5·06	0·0173 0·0266	108·9	54·0
ford Haven $= 0{\cdot}031x - 1{\cdot}17$	86 140	1·48 3·14	0·0172 0·0224	112·6	30·6
vestoft Steam $= 0{\cdot}044x - 1{\cdot}62$	86 110	2·15 3·20	0·0250 0·0291	48·9	16·4
vestoft Motor $= 0{\cdot}049x - 1{\cdot}55$	70 100	1·86 3·32	0·0265 0·0332	78·6	25·1

Ships and Regressions	Limits of Horse Power	Fishing Power	Fishing Power per Unit Horse Power	Range of variation %	
				Fishing Power	Fishing Power /Horse Power
lpen Bank (all ships) $= 0{\cdot}038x + 9{\cdot}26$	90 200	12·65 16·79	0·141 0·084	32·7	67·4
land $= 0{\cdot}025x + 0{\cdot}416$	80 200	2·45 5·50	0·0306 0·0275	124·6	11·3
lford Haven $= 0{\cdot}020x + 1{\cdot}02$	35 100	1·73 3·04	0·0495 0·0304	75·8	62·5
westoft Steam $= 0{\cdot}032x + 1{\cdot}14$	35 60	2·28 3·09	0·0651 0·0515	35·6	26·5
westoft Motor $= 0{\cdot}005x + 1{\cdot}22$	150 400	2·04 3·40	0·0136 0·0085	66·6	60·0

te: Horse power is the nominal horse power for all groups except Lowestoft motor trawlers, for which brake horse power has been used.

Table 8: *Measures of fishing time for different sizes of trawlers fishing at Skolpen Ban October-December*, 1951

Tonnage Class	Number of ships	Length of Trip (days)	Hours Fishing per trip	Fishing: Days Absence
		October		
< 430	10	23·4	150·5	6·43
430 – 499	12	23·0	166·8	7·25
500 – 599	11	22·6	156·8	6·96
600 – 699	8	22·0	164·8	7·49
> 700	4	21·8	172·0	7·91
		November		
< 430	11	23·9	159·1	6·65
430 – 499	13	23·3	177·1	7·60
500 – 599	22	23·0	160·3	6·98
600 – 699	16	23·1	174·3	7·56
> 700	9	22·9	173·7	7·58
		December		
< 430	18	24·2	137·2	5·66
430 – 499	21	23·7	151·0	6·38
500 – 599	17	23·1	151·4	6·56
600 – 699	18	22·8	145·6	6·38
> 700	10	23·3	166·5	7·15

Table 9: *Catch, effort and catch per unit effort of certain trawlers fishing at the same rectan at Iceland during the same months of* 1946 *and* 1951

Ship	Year	Days Absent	Hours Fishing	Weight landed (cwt.)			Catch of cod		Ratio 1951 1946 of	
				Cod	Haddock	Total	per day	per hour	cwt./day	cwt./h
1	1946	22	52	2052*	302†	2618	93·3	39·46	0·344	0·078
	1951	20	210	642	709	1874	32·1	3·06		
2	1946	24	88	864*	1128*	2493	36·0	9·82	1·661	1·252
	1951	23	112	1376	311	1836	59·8	12·29		
3	1946	22	45	1244*	686*	2242	56·5	27·64	0·358	0·185
	1951	19	75	383	624	1494	20·2	5·11		
4	1946	21	62	2989†	2125†	6128	142·3	48·21	0·187	0·105
	1951	26	136	691	798	1935	26·6	5·08		
5	1946	25	88	1840	46	2284	73·6	20·91	0·647	0·360
	1951	19	120	904	228	1544	47·6	7·53		
6	1946	24	88	1750†	750†	2983	72·9	19·89	0·365	0·219
	1951	21	128	558	826	2020	26·6	4·36		
7	1946	21	92	1748*	946*	3178	83·2	19·00	0·560	0·408
	1951	22	120	935	568	1903	} 46·6(a)	7·76(a)		
	1951	20	132	1021	464	2399				
8	1946	19	75	934	160	1423	49·2	12·45	1·352	0·842
	1951	23	146	1530	2	1988	66·5	10·48		

* All of the catch consisted of headless fish.
† Part of the catch consisted of headless fish.
(a) Mean for the two trips in 1951 taken.

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